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PARTICLE SIZING IN A FUEL-RICH RAMJET COMBUSTOR(U)

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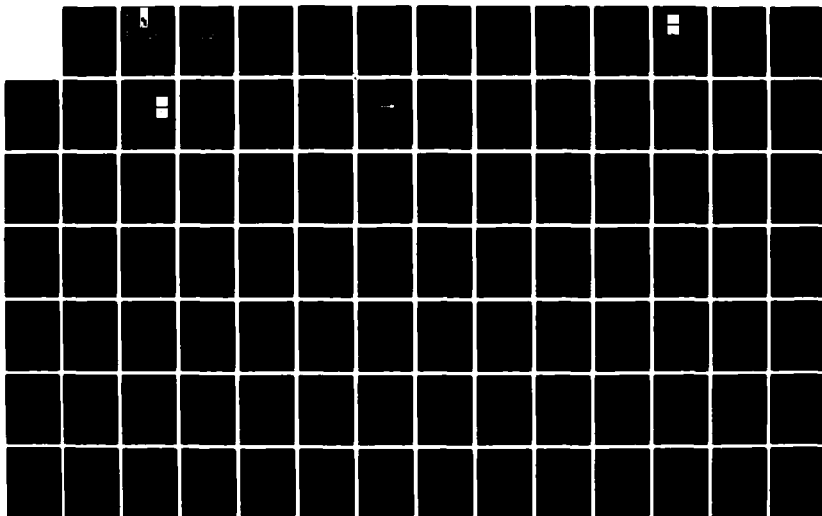
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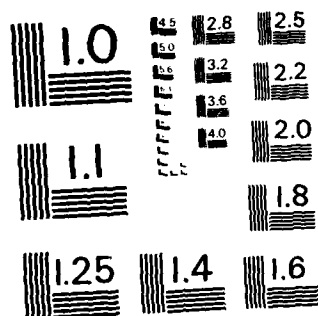
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*Technical Memorandum*

## PARTICLE SIZING IN A FUEL-RICH RAMJET COMBUSTOR

R. TURNER  
R. A. MURPHY

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R. TURNER  
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THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY  
Johns Hopkins Road, Laurel, Maryland 20707  
Operating under Contract N00024-83-C-5301 with the Department of the Navy

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <p>A laser Doppler velocimeter (LDV) has been used to measure the size, concentration, and velocity of individual particles having diameters ranging from 3 to greater than 100 <math>\mu\text{m}</math> and having velocities of 600 to 1400 m/s in the fuel-rich exhaust of a ramjet combustor. The visibility of the LDV output was used to measure particle diameters ranging from 3 to under 30 <math>\mu\text{m}</math> and the mean scattered amplitude was used to measure particles ranging from 20 to over 100 <math>\mu\text{m}</math>. The attenuation of one LDV beam provided information on the total amount of material present. Measurements were made along the flow field of a combustor operating at 35 psia, an inlet temperature of 650 to 850 K, and fuel equivalence ratios (ER) of 1.6 and 2.6. Typically, at a point one-half inch from the nozzle and for an ER of 2.6, the average particle velocity is 800 m/s, the average particle size is 50 <math>\mu\text{m}</math>, and the particle density is 250 particles per cubic centimeter. The large particles appear to be unburnt fuel.</p>		

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## 1. INTRODUCTION

Nonintrusive diagnostic techniques are becoming more and more necessary in the study of combustion processes and high-speed flow fields. Nonintrusive diagnostics usually involve optical techniques and while those techniques can provide high data rates, good spatial resolution, and usually do not perturb the flow, their application presents problems unique to the particular optical technique and configuration used. The following report describes the development and preliminary tests of an instrument to measure the size and speed of single, large particles in the 3 to 100  $\mu\text{m}$  range, in a supersonic flow. The number of particles (which consist of unburnt or partially burnt fuel droplets and possibly agglomerations of unburnt particles) in this size range and their evolution with time are of particular concern in the fuel-rich supersonic combustors now under development.

A variety of techniques has been developed that use light scattering to measure the size of particles such as the products of combustion or aerosols. In general, all of the available techniques make important assumptions that may include particle size distribution, particle shape, index of refraction, or particle

size relative to the wavelength of the light source. Some techniques require an actual sampling of the flow for sizing measurements. Some methods use relative amplitude measurements while others use absolute measurements. Some measurements are for a single particle, others derive the results from a larger number of particles of various sizes. The method chosen depends largely on what parameters are important and on how well a system can be configured for the particular application. For our application it was decided that the information available from a standard laser Doppler velocimeter (LDV) be used to provide a simultaneous measurement of both the size and the speed of single particles in the flow. The LDV was originally developed to measure the velocity of particles in the flow and it is usually one of the first instruments considered for use in the present type of application. Only recently, however, has work been undertaken to use the information that the LDV provides to obtain particle size as well as the velocity. The high speeds and hostile environment encountered in a supersonic combustor present unique problems for this application.

## 2. LDV OPERATION

Figure 1 is a schematic diagram of the Thermo-Systems Inc. (TSI) LDV (configured for forward scattering) that is used for particulate sizing. The output of a 5 mW, helium-neon, vertically polarized laser (with a wavelength of  $0.6328 \mu\text{m}$ ) is split into two beams of equal intensity that are focused to cross 250 mm from the lens at an angle of  $2^\circ$ . A particle at the intersection of the two beams will scatter light from each beam. The phase relationship between the two scattered signals as they appear at the light collector (in this case a photomultiplier (PMT)) depends on the particle's position relative to each beam, making both constructive and destructive interference possible. Even though the actual interference is measured at the detector, it is often convenient to think of the scattering volume as illuminated by a series of light and dark fringes produced by interference at the intersection of the two beams. The ellipsoidally shaped scattering volume ( $1.2 \times 10^{-4} \text{ cm}^3$ ) is determined by the beam width of the focused laser, an aperture ( $250 \mu\text{m}$  diameter) located at the focal point in the collection optics, and the viewing angle. The minor axis of the ellipsoid, parallel to the flow, is  $250 \mu\text{m}$ ; the major axis, perpendicular to the flow, is  $0.2 \text{ mm}$ . Where high particle densities are anticipated, as they are in this application, it is desirable

to minimize the scattering volume to permit a sufficiently high count rate of single particles. If two or more resolvable particles above a given size are present at the same time in the scattering volume, the instrument will not process them. The aperture in the collection optics limits the field of view at the center of the region to 16 vertical interference fringes that are spaced  $17.6 \mu\text{m}$  apart. The fringe spacing ( $\delta_f$  in  $\mu\text{m}$ ) is given by

$$\delta_f = \frac{\lambda}{2\sin\gamma}, \quad (1)$$

where  $\lambda$  is the wavelength in  $\mu\text{m}$  and  $\gamma$  is one-half the angle between the two LDV beams. The plane of the fringes is parallel to the flow.

A particle moving through the scattering volume will produce a scattered light signal that is modulated at a frequency ( $f$ ) proportional to  $\delta_f$ , and its component of velocity ( $v$ ) perpendicular to the fringes. The modulation frequency is given by

$$f = \frac{v}{\delta_f} = 5.68 \times 10^{-2} v, \quad (2)$$

where  $f$  is in megahertz,  $v$  in meters per second, and

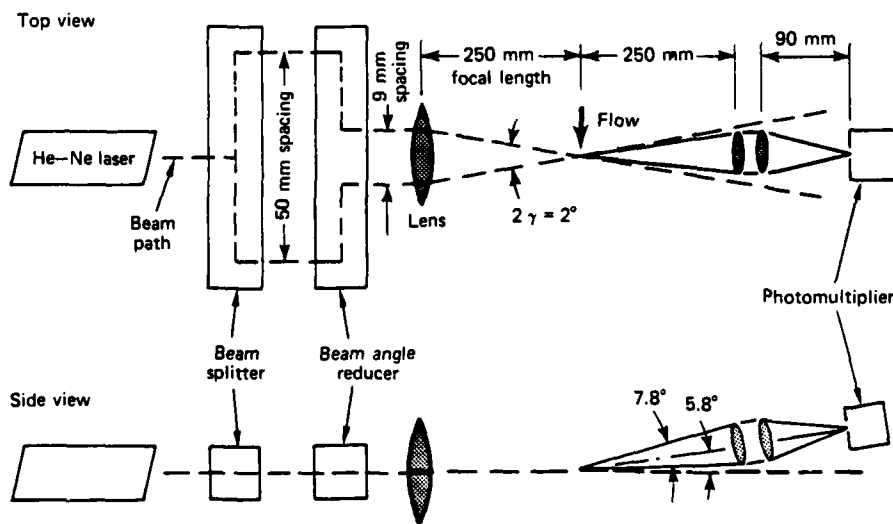


Figure 1 - LDV optical configuration.

$\delta$ , is in micrometers. Particles moving at the speeds expected in actual combustors (600 to 1400 m/s) will produce scattered light pulses from 0.18 to 0.4  $\mu$ s wide that are modulated at frequencies of 30 to 80 MHz. The actual choice of the LDV parameters involves a series of compromises. The beam width, crossing angle, aperture stop, and scattering angle determine the scattering volume and thus the number of particles that can be counted. In this case, the modulation frequency is as high as practical for the anticipated velocities. Reducing the crossing angle reduces the frequency at the expense of increasing the scattering volume.

The size of the particle producing the scattered light signal can be derived from the mean amplitude of the signal and the ratio of the depth of modulation of the scattered signal to the mean amplitude. The latter is often referred to as the visibility of the signal. Visibility is defined as  $(I_{\max} - I_{\min}) / (I_{\max} + I_{\min})$ , where  $I_{\max}$  and  $I_{\min}$  are, respectively, the maximum and the minimum light intensity measured near the maximum signal of each scattered light pulse. Figure 2 shows two high-visibility signals measured under two different conditions. In Fig. 2a, obtained from fuel droplets in the test combustor, the visibility is 0.67; in Fig. 2b, obtained with dioctyl phthalate (DOP) aerosols, the visibility is 0.79. The two measurements of particle size are complimentary: the intensity of light scattered by small particles ( $< 3 \mu$ m in the present case) is low, but the visibility is high (approx. 1); the intensity of light scattered by large particles ( $> 30 \mu$ m) is large, but the visibility is low ( $< 0.3$ ). There are other important differences. The intensity is an absolute measurement and generally

increases monotonically (for some optical configurations) with size. The visibility is a relative measurement and can be multivalued as the particle size increases. The dynamic range of the visibility in most cases is probably less than 10:1, whereas the dynamic range of intensity measurements can be much greater and can present a problem in this application. The intensity measurement has been the conventional method used to size particles<sup>1,2</sup>; the use of signal visibility for particle sizing is of fairly recent origin and the various aspects of its application and interpretation are considered in Refs. 3 through 16. Durst presents a recent comprehensive review of the use of the visibility technique<sup>6</sup>. The visibility measurement has been emphasized in this work because the range of sizes that can be measured can be controlled by the proper choice of optical components and angular position of the detector and because the particle sizes anticipated in actual combustors were in a range compatible with practical LDV configurations.

Equation 3 is an expression for the visibility ( $V$ ), assuming that the particles are nonuniformly illuminated by the interference fringes in the scattering volume, has been derived by Farmer<sup>1</sup>. Because of the assumption involved, Eq. 3 is limited to near-zero scattering angles, small crossing angles, and large collection apertures. The visibility can be calculated for spherical particles from

$$V = \frac{2J_1(\pi D/\delta)}{\pi D/\delta}, \quad (3)$$

where  $J_1$  is the first-order Bessel function,  $D$  is the particle diameter, and  $\delta$ , is the fringe spacing.

<sup>1</sup>D. Holve and S. A. Self, "Optical Particle Sizing for *in situ* Measurements," Parts 1 and 2, *Appl. Opt.*, **18**, 1632 (1979).

<sup>2</sup>D. Holve, "In *situ* Optical Particle Sizing Technique," *J. Energy*, **4**, 176 (1980).

<sup>3</sup>W. M. Farmer, "Measurement of Particle Size, Number Density, and Velocity Using a Laser Interferometer," *Appl. Opt.*, **11**, 2603 (1972).

<sup>4</sup>W. M. Farmer, "Observations of Large Particles with a Laser Interferometer," *Appl. Opt.*, **13**, 610 (1974).

<sup>5</sup>W. M. Farmer, "Visibility of Large Spheres Observed with a Laser Velocimeter: A Simple Model," *Appl. Opt.*, **19**, 3660 (1980).

<sup>6</sup>E. Durst, "Review - Combined Measurements of Particle Velocities, Size Distributions, and Concentrations," *J. Fluids Eng.*, **104**, 284 (1982).

<sup>7</sup>N. A. Chigier, A. Ungut, and A. J. Yule, "Particle Size and Velocity Measurement in Flames by Laser Anemometry," *Proc. 17th Symp. on Combustion*, The Combustion Institute, Pittsburgh, p. 315 (1978).

<sup>8</sup>A. J. Yule, C. Ah Seng, P. G. Felton, A. Ungut, and N. A. Chigier, "A Laser Tomographic Investigation of Fuel Sprays," *Proc. 18th Symp. on Combustion*, The Combustion Institute, Pittsburgh, p. 1501 (1981).

<sup>9</sup>R. J. Adrian and K. L. Orloff, "Laser Anemometer Signals:

Visibility Characteristics and Application to Particle Sizing," *Appl. Opt.*, **16**, 677 (1977).

<sup>10</sup>A. R. Jones, "Light Scattering by a Cylinder Situated in an Interference Pattern, with Relevance to Fringe Anemometry and Particle Sizing," *J. Phys. D: Appl. Phys.*, **6**, 417 (1973).

<sup>11</sup>A. R. Jones, "Light Scattering by a Sphere Situated in an Interference Pattern, with Relevance to Fringe Anemometry and Particle Sizing," *J. Phys. D: Appl. Phys.*, **7**, 1369 (1974).

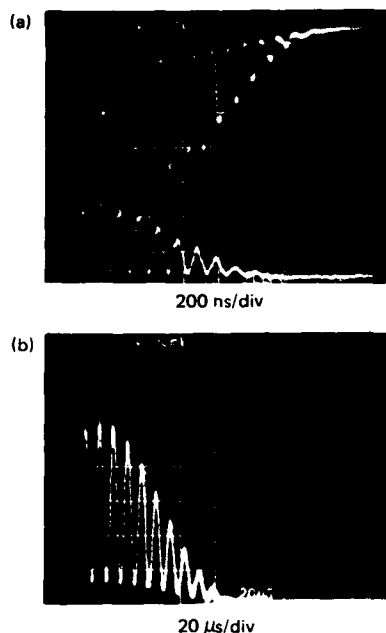
<sup>12</sup>N. S. Hong and A. R. Jones, "A Light Scattering Technique for Particle Sizing Based on Laser Fringe Anemometry," *J. Phys. D: Appl. Phys.*, **9**, 1839 (1976).

<sup>13</sup>M. S. Atakan and A. R. Jones, "Measurement of Particle Size and Refractive Index Using Crossed-Beam Laser Interferometry," *J. Phys. D: Appl. Phys.*, **15**, 1 (1982).

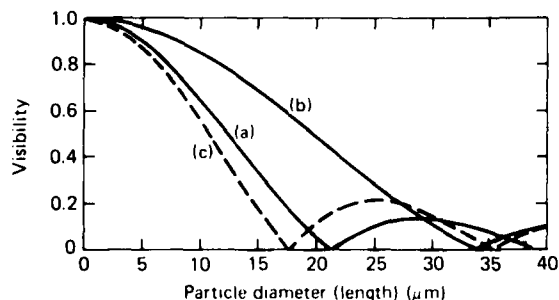
<sup>14</sup>A. J. Yule, N. A. Chigier, S. Atakan, and A. Ungut, "Particle Size and Velocity Measurement by Laser Anemometry," *J. Energy*, **1**, 4 (1977).

<sup>15</sup>D. M. Odgen and D. E. Stock, "Simultaneous Measurement of Particle Size and Velocity via the Scattered Light Intensity of a Real Fringe Anemometer," *Laser Velocimetry and Particle Sizing*, H. D. Thompson and W. H. Stevenson eds., Hemisphere Publishing, Washington, p. 496 (1979).

<sup>16</sup>N. A. Chigier, A. Ungut, and A. J. Yule, "Particle Sizing in Flames with Laser Velocimeters," *ibid.*, **22**, p. 416.



**Figure 2** – Typical high visibility signals obtained from the LDV in the forward scattering position. (a) This signal was obtained from a fuel-air mixture in the test combustor; the particle, having a diameter (derived from the visibility of the signal) of 15  $\mu\text{m}$  is moving at 180 m/s. (b) The particle is a 12  $\mu\text{m}$  DOP aerosol moving at 2.1 m/s.



**Figure 3** – Visibility plotted as a function of particle diameter (or length) using Farmer's approximation<sup>5</sup>. (a) Where particles are spherical and the beam-crossing angle is 2° ( $\delta_f = 17.6 \mu\text{m}$ ). (b) Where particles are spherical and the beam-crossing angle is 1.3° ( $\delta_f = 27.9 \mu\text{m}$ ). (c) Where particles are cylindrical and the beam-crossing angle is 2°.

In the present configuration, the visibility becomes

$$V = 2J_1(0.178D)/0.178D. \quad (4)$$

Figure 3 contains two plots of the visibility computed using Eq. 3 for the nominal crossing angle of 2° (curve *a*) and for a crossing angle of 1.3° (curve *b*), which is obtained by changing the focal length of the input lens from 250 to 400 mm. By this means the size range covered by the visibility technique can be extended to handle larger sized particles at the cost of reduced scattered light intensity. The visibility for cylindrically shaped particles is

$$V = \frac{\sin(\pi D/\delta_f)}{\pi D/\delta_f}, \quad (5)$$

where *D* in this case is one-half the length of the cylinder. The visibility for a cylinder is plotted as curve *c* for the same fringe spacing as curve *a*. Despite the smaller area that a cylinder can present compared to a sphere, the visibilities for the sphere and cylinder are not very different.

Equations 3 and 5, if used within their limitations, can give an indication of the particle sizes involved. However, the visibility and the scattered light intensity are both extremely sensitive to the *F* number of the collection optics and the location of the optics relative to the incident laser beams. In fact, the visibility and intensities as functions of the particle diameter can be tailored (as will be shown) by choosing the optical configuration to suit the expected experimental conditions. These limitations and the limitations of Eqs. 3 and 5 have been considered in detail by many authors, and in particular, the authors of Refs. 17 and 18. Because of these facts, it is extremely important that the instrument be calibrated accurately for the conditions under which it will be used and that the response function of the instrument can be predicted accurately. The response function is the PMT output signal produced by a given sized particle and is a function of the scattering angle, limiting aperture of the collection optics, and the focal length of the collection lens. A major portion of this work was devoted to the problems of calculating the response function and of calibrating the overall system.

<sup>17</sup> D. M. Robinson and W. P. Chu, "Diffraction Analysis of Doppler Signal Characteristics for a Cross-Beam Laser Doppler Velocimeter," *Appl. Opt.*, **14**, 2177 (1975).

<sup>18</sup> W. P. Chu and D. M. Robinson, "Scattering from a Moving Spherical Particle by Two Crossed Coherent Plane Waves," *Appl. Opt.*, **16**, 619 (1977).

### 3. RESPONSE FUNCTION CALCULATION

Calculating the response function requires integrating the scattered light over the solid angle defined by the aperture and focal length of the collection optics. The intensity of the light scattered in any direction is a function of the scattering angle, the shape of the particle, its index of refraction, and the polarization of the incident light. The Mie theory<sup>19,20</sup> is the only exact theory available and it applies only to spherical particles. The intensity of the scattered signal, particularly for small particles with real indexes of refraction, can be very structured with deep fluctuations as the scattering angle changes. The Mie theory calculation becomes expensive for large sized particles because of the large number of terms that are required in the expansions used; the number of terms is approximately equal to alpha ( $\alpha = \pi D/\lambda$ ), a conventional scale factor, and so is proportional to the particle diameter. There are simpler approximations that generally divide the problem into three components contributing to the scattered light: diffraction, refraction, and reflection. The contribution of each component depends on the particle size, index of refraction, and scattering angle; some of the approaches in this direction are listed in Refs. 21 through 24. Farmer<sup>21</sup>, in particular, and Bachalo<sup>22</sup> have tried to extend the visibility approach to angles other than forward scattering, but all these approximations, because of their limitations, present uncertainties in applications of this type.

Because two beams are used in the LDV, the vector components  $E_x$  and  $E_y$  of the scattered light for each

beam must be calculated and then transformed into a common scattering plane where the components can be added vectorially. The scattering geometry used to calculate the visibility and the mean intensity are shown in Fig. 4. The scatterer is located at the origin (0) and the two laser beams crossing at an angle of  $2\gamma$  in the Y-Z plane are indicated by the propagation vectors  $k_1$  and  $k_2$ . The laser is vertically polarized with its electric field vector ( $E_z$ ) parallel to O-X. The three scattering planes considered are indicated as 0-1-3 for the left beam, 0-2-4 for the right beam, and 0-3-5 for the combined scattering plane.

The electric vector components that are parallel to a scattering plane are designated by 2 and those perpendicular to the scattering plane by 1 (this designation is a fairly standard convention). The electric field components are indicated as follows:  $E(2)$  and  $E(1)$ , the parallel and perpendicular components in the combined scattering plane;  $E2(1)$  and  $E2(2)$ , the parallel components from beams 1 and 2, respectively, in their respective planes; and  $E1(1)$  and  $E1(2)$  are the corresponding perpendicular components. The parallel and perpendicular components of the scattered field are added vectorially in the combined plane to give the resulting perpendicular and parallel components. The electric field vectors are used, in turn, to compute the total collected power. The maximum and minimum collected intensities from which the visibility and the mean scattered intensity are calculated are obtained first by adding the components from beams 1 and 2 in phase to give the maximum signal and then subtracting them (the phase of beam 2 is shifted  $180^\circ$ ) to give the minimum signal.

The integration is indicated by

$$P/2I_0 = \int_0^{2\pi} d\phi \int_0^{\pi/2} F(\theta, \phi) \sin\theta d\theta, \quad (6)$$

where  $P$  is the collected power and  $I_0$  is the total incident laser power. A more standard form is

$$P/2I_0 = \int_0^{2\pi} d\phi \int_0^{\pi/2} [I_1(\theta) \sin^2\phi + I_2(\theta) \cos^2\phi] \sin\theta d\theta. \quad (7)$$

- <sup>19</sup>H. C. van de Hulst, *Light Scattering by Small Particles*, Dover Publications, New York, p.121 (1981).
- <sup>20</sup>M. Born and E. Wolf, *Principles of Optics*, 5th ed., Pergamon Press, Oxford, p. 633 (1975).
- <sup>21</sup>J. McK. Ellison and C. V. Peetz, "The Forward Scattering of Light by Spheres According to Geometrical Optics," *Proc. Phys. Soc. (London)*, **67A**, 105 (1959).
- <sup>22</sup>J. R. Hodgkinson and I. Greenleaves, "Computations of Light-Scattering and Extinction by Spheres According to Diffraction and Geometrical Optics and Some Comparison with the Mie Theory," *J. Opt. Soc. Am.*, **53**, 577 (1963).
- <sup>23</sup>A. Ungut, G. Grehan, and G. Gouesbet, "Comparison Between Geometrical Optics and Lorenz-Mie Theory," *Appl. Opt.*, **17**, 2911 (1981).
- <sup>24</sup>J. D. Pendleton, "Mie and Refraction Theory Comparison for Particle Sizing with the Laser Velocimeter," *Appl. Opt.*, **21**, 684 (1982).
- <sup>25</sup>W. D. Bachalo, "Method for Measuring the Size and Velocity of Spheres by Dual-Beam Light-Scatter Interferometry," *Appl. Opt.*, **19**, 363 (1980).

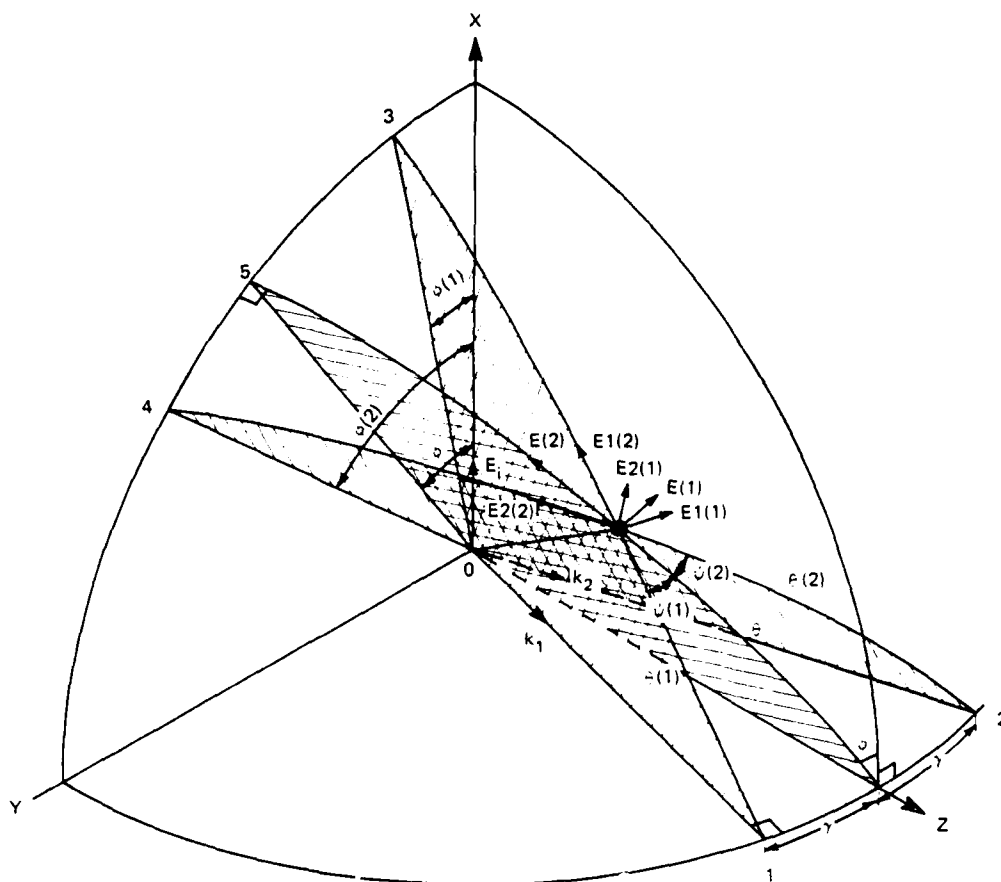


Figure 4 - Geometrical configuration of the LDV beams and their scattered vector components.

The integration is over a circular aperture centered in the X-0-Z plane and above the Y-0-Z plane (the actual program does not have this last restriction), where the upper limit is calculated by

$$\theta(u) = \cos \left[ \cos \left( \frac{a}{z} \right) - \frac{\cos \theta \cos(\theta_{min} + a/z)}{\sin \theta \sin(\theta_{min} + a/z)} \right], \quad (8)$$

where  $a$  is the aperture radius,  $z$  is the focal length, and  $\theta_{min}$  is the minimum aperture angle.  $I_1(\theta)$  and  $I_2(\theta)$  are the perpendicular and parallel scattered intensities in the combined scattering plane. The intensities  $I_1$  and  $I_2$  are related to the scattered field intensities:

$$\begin{aligned} I_1(\theta) &= |S_1(\theta)|^2 \\ I_2(\theta) &= |S_2(\theta)|^2 \end{aligned} \quad (9)$$

The simplest approximation applicable to large particles at very small forward scattering angles is the diffraction approximation<sup>1,2</sup>. In this case,

$$S_1(\theta) = S_2(\theta) = \frac{k^2 d^2}{4} \frac{J_1(x)}{x},$$

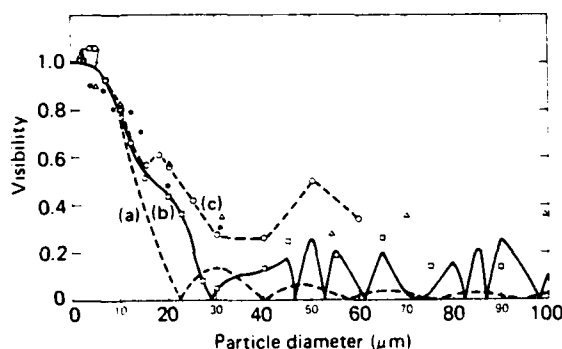
where

$$x = \frac{k d \sin \theta}{2} \quad (10)$$

The diffraction approximation does not include the contributions to the scattered light that are caused by the optical properties of the particle (a hole or a similarly shaped opaque mask will produce the same diffraction pattern). Appendix A lists the Fortran program used to calculate the visibility and collected power from a spherical particle, using the diffraction approximation. The calculated visibility and intensity for a scattering angle of  $5.8^\circ$  (which is the normal forward scattering angle used in calibration and tests) are plotted in Figs. 5 and 6. The differences between the visibility calculated in this fashion (curve 5b) and the visibility derived from Farmer's equation (curve 5a) can be clearly seen. With the aperture and the scattering angle used, a large fraction of the scattered light (particularly for the larger sized particles) is not collected.

It is clear from the above results that a more exact calculation is required even at these small scattering angles. Several programs have been developed to calculate the required Mie coefficients,  $S_1$  and  $S_2$ .

Appendix B lists the Fortran program that incorporates a Mie program developed by Grehan and Gouesbet<sup>26,27</sup>. This version has the advantage that it

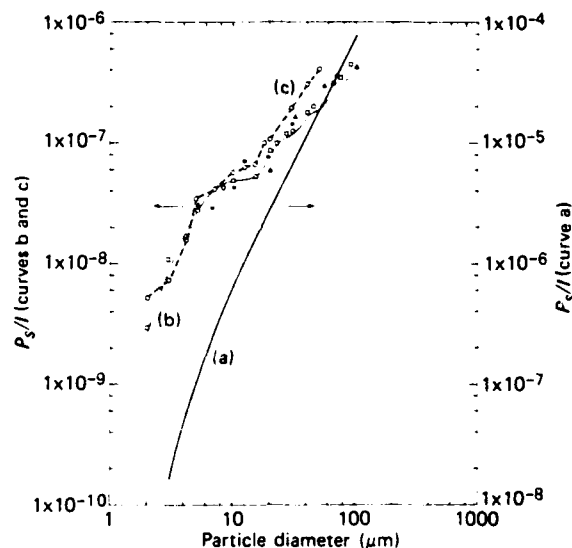


**Figure 5** - Calculated and measured visibility plotted as a function of particle diameter. The plotted data, except for (a), are for a detector with a 250 mm focal length, with a 34 mm aperture, a scattering angle of  $5.8^\circ$ , and a beam-crossing angle of  $2^\circ$ . Derivation of the curves is as follows: (a) The calculated visibility using Farmer's approximations; (b) The calculated visibility using the diffraction approximations (Appendix A); and (c) The calculated visibility using the Mie Theory (Appendix B) for DOP.  $\circ$  Mie calculation for DOP,  $n = 1.49 - i0.00$ ;  $\square$  Mie calculation for soot/hydrocarbon,  $n = 1.67 - i0.33$ ;  $\Delta$  measured values (relative) for polystyrene spheres,  $n = 1.59 - i0.00$ ; and  $*$  measured values (relative) to DOP aerosols.

<sup>26</sup>G. Grehan and G. Gouesbet, "Mie Theory Calculation: New Progress, with Emphasis on Particle Sizing," *Appl. Opt.*, 18, 3489 (1979).

<sup>27</sup>G. Grehan and G. Gouesbet, "SUPERMIDI" Report TFI 79 20 03, Laboratoire de Thermodynamique, Université de Rouen 6130 Mont-Saint-Aignan, France.

can handle indexes of refraction having large imaginary components. The visibilities and mean scattered intensities calculated with the Fortran program in Appendix B for DOP and a soot-hydrocarbon mixture for selected diameters are shown in Figs. 5 and 6. DOP has an index of refraction  $n = 1.49 - i0.00$  and was chosen because it was used to calibrate the instrument. The soot-hydrocarbon mixture, which has an index of refraction  $n = 1.67 - i0.33$ , was chosen because it is assumed to be representative of the partially burned combustion products present in the flame. The results indicate that the diffraction approximation is reasonable for sizing partially burnt fuel; the imaginary component of the index reduces the effects of the optical properties of the particle. However, the effect of the index of refraction must be considered in the calibration, the choice of scattering angle, and the sizing of fuel droplets in both the case of visibility and the mean scattered intensity. A very recent and related calculation for a variety of



**Figure 6** - Calculated and measured values of the mean scattered intensity as a function of particle size. The plotted data, except for (a), are for a detector with a 250 mm focal length lens and a 34 mm aperture located  $5.8^\circ$  above the plane of the LDV beams. The beam-crossing angle is  $2^\circ$  and the fringe spacing is  $17.6 \mu\text{m}$ . Derivation of the curves is as follows: (a) Intensity was calculated using the diffraction approximation (Appendix A) with the detector centered between the beams in the plane of the LDV beams. (b) Intensity was calculated using the diffraction approximation. (c) Intensity was calculated using the Mie Theory (Appendix B) for DOP.  $\circ$  Mie calculation for DOP,  $n = 1.49 - i0.00$ ;  $\square$  Mie calculation for soot/hydrocarbon,  $n = 1.67 - i0.33$ ;  $\Delta$  measured values (relative) for polystyrene spheres,  $n = 1.59 - i0.00$ ; and  $*$  measured values (relative) to DOP aerosols.

aperture conditions is reported in Ref. 4, the possibilities of tailoring the system for a particular visibility vs. particle diameter is clearly indicated.

The more exact program has been used to calculate visibility and intensity at 90 and 160°, which are two regions where visibility measurements in particular would be desirable and where any approximations are suspect. Figure 7 is a plot of the visibility for scattering angles of 90 and 160° using Farmer's approximate formulas<sup>5</sup>. At these angles the size range that can be measured can be tailored, within the experimental constraints, by choosing the  $F$  number of the collection optics. For the case of 90° side scattering, the visibility computed from Farmer's formula for a 48  $\mu\text{m}$  DOP particle is 0.83 and that calculated with the exact theory is 0.7. These agree reasonably well with the measured visibility of 0.88. For the case of 160° backscattering (the maximum backscattering angle less than 180° that could be accommodated in the present setup) the results are not as good. This

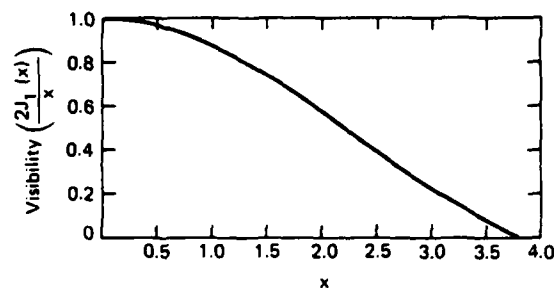


Figure 7 - Visibility versus scale factor ( $x$ ) for side and backscattering conditions using Farmer's approximation<sup>5</sup>. The focal length is 120 mm, the aperture is 34 mm and  $F$  is 3.5. For 90° scattering,  $x = 2\pi(D/\lambda)/4F$ , where  $F$  is the  $F$  number of the collection optics and  $D = 29.4x$ . For 160° scattering,  $x = \pi(D/\lambda)/4F(1 + 1/2 \tan^2 \delta)$ , where  $\delta$  is the scattering angle and  $D = 84.0x$ .

time the visibility from Farmer's formula for a 48  $\mu\text{m}$  DOP particle is 0.96, the calculated value with the Mie theory is 0.32, and the measured value is 0.7. The limitations on the measured values are discussed later.

<sup>5</sup>C. R. Negus and L. E. Drain, "Mie Calculations of the Scattered Light from a Spherical Particle Traversing a Fringe Pattern Produced by Two Intersecting Laser Beams," *J. Phys. D: Appl. Phys.*, 15, 375 (1982).



#### 4. PSI CALIBRATION

Three methods have been used to calibrate the PSI over velocities ranging from 3 to 400 m/s: (a) polystyrene spheres 5 to 100  $\mu\text{m}$  in diameter, (b) DOP aerosols 1 to 50  $\mu\text{m}$  in diameter, and (c) aluminum oxide particles approximately 5 to 25  $\mu\text{m}$  in diameter. Unfortunately no facilities were available for calibrating at the speeds encountered in the actual combustor; therefore, for this calibration a simulated signal (described in detail in Appendix C) was inserted at the PMT output. The simulated signal could be adjusted to vary the pulse width, the amplitude, the fringe frequency, and the number of modulation fringes.

The polystyrene spheres (index of refraction,  $n = 1.59 - i0.00$ ) were electrostatically attached to a 250  $\mu\text{m}$  thick glass microscope slide, which in turn was mounted on a rotating wheel. With this technique, the PSI signal can be identified with a particle whose size, shape, and index of refraction as well as position in the scattering volume are known. Speeds of up to 20 m/s were used. Figure 8a shows an image of a 31  $\mu\text{m}$  particle centered in the LDV scattering volume (the actual fringe spacing can be obtained from this photograph.). Figure 8b shows the PMT output signal when the particle is moved through the scattering volume at 20 m/s. The results of these measurements are plotted on Figs. 5 and 6 and agree well with the Mie calculations.

A Berglund-Liu aerosol generator (Thermal Systems, Inc., Model 3050) operated in both the upright and the inverted positions (with 20 and 50  $\mu\text{m}$  orifices and with DOP concentrations in alcohol of up to 10%) was used to provide aerosols from 4 to 48  $\mu\text{m}$  in diameter. It was difficult, however, to get a reliable supply of the larger sized aerosols from the generator. The sizes of the aerosols produced were routinely measured with a microscope. During these measurements, an impact spreading factor of 3, as indicated in Ref. 29, was independently confirmed. The Berglund-Liu aerosol generator was used because of the uncertainties associated with the spheres mounted on substrates and to provide a larger number of particles moving at higher speeds than would be available otherwise. The data obtained with the DOP

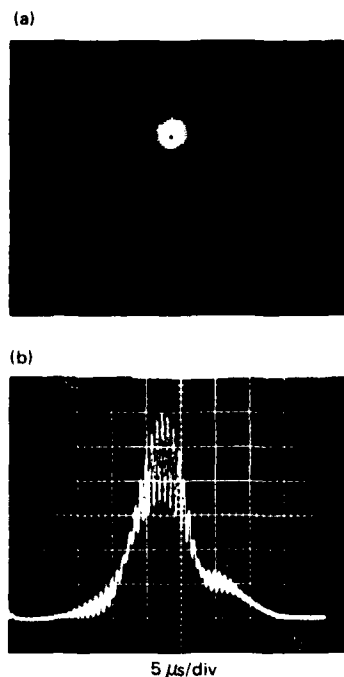


Figure 8 — (a) Image of 31  $\mu\text{m}$  polystyrene sphere in the 17.6  $\mu\text{m}$  fringe system; (b) PMT output produced by the 31  $\mu\text{m}$  sphere mounted on a rotating glass slide.

aerosols moving at 3 m/s (the typical speed of the aerosols leaving the generator) are plotted on Figs. 5 and 6. These data show agreement with the results obtained with polystyrene, but again indicate the sensitivity of the results to the index of refraction. The output of the aerosol generator was injected into a small supersonic air jet, which gave particle speeds of up to 400 m/s. The sizing measurements with particles up to 8  $\mu\text{m}$  in diameter moving at 300 m/s agreed with the results obtained for the same size particles moving at 3 m/s. However, the results obtained when the larger particles were used did not agree with the results for the large sized particles at low speed. The PSI measurements and limited microscopic measurements indicated that the large sized particles were probably breaking up in the high-speed constricted flow.

<sup>29</sup>B. Y. H. Liu, D. Y. H. Pui, and Xian-Qing Wang, "Drop Size of Liquid Aerosols," *Atmos. Environ.*, **16**, 563 (1982).

The results with aluminum oxide particles were consistent with the results for DOP and polystyrene, but were much more erratic because the distribution of particles sizes was large and the particle shapes were very irregular.

The calibration at scattering angles of 90 and 160° was limited to a single size (48  $\mu\text{m}$  DOP) because of time restrictions and the lack of suitable larger parti-

cles. The 90° visibility results agree well, as discussed before, but the 160° results did not agree as well. There were additional problems because of the reduced scattered signal even for the larger particles and at 90° alignment problems became significant. Additional calibration points are required before these scattering angles can be used with any confidence.

## 5. PARTICLE SIZING INSTRUMENTATION

Figure 9 is a detailed block diagram of the particle sizing instrumentation used to select suitable individual particles and to derive the size and speed information from the selected particles. The collected light is detected with an RCA type 4526 PMT, which is normally operated at -900 V (-1100 V was used for the 90 and 160° scattering angles). The thresholds and saturation limits within the system required that the signal at this point be in the range of 15 to 700 mV. The PMT output is amplified ten times and then filtered by a low-pass filter (with a cutoff frequency of 5 MHz) to remove the high-frequency modulation and to provide the mean value of the scattered intensity  $(I_{\text{max}} + I_{\text{min}})/2$ . The PMT output is also filtered by a band-pass filter (having a band pass from 20 to 100 MHz) to obtain the high-frequency modulation. The resulting AC signal is peak detected with a HP 8470B crystal detector with a matching 50  $\Omega$  load to provide  $(I_{\text{max}} - I_{\text{min}})/2$ . The detected pulse is run through a fast source follower (National Semiconductor LH0063C), inverted to provide a positive-going pulse, and amplified ten times. If a negative-going gate pulse (indicating no pulse pile-up) is present at this point, the two pulses are stretched to the length of the gate pulse (0.6  $\mu\text{s}$ ) and fed to the peak-sense-and-hold module (Optical Electronics Inc., Model 5030A). This module receives both a gate pulse and a reset pulse. During the time that both are

present, the circuit acquires the most positive value of the input signal. Thereafter, the circuit is insensitive to changes in the input signal and holds its peak value for the duration of the reset pulse. The input pulse, if it is an acceptable pulse, is gated on through a linear gated amplifier.

The amplified output of the bandpass filter is also sent to two fast discriminators (LeCroy Research Systems, LRS-161, 100 MHz) that provide narrow (5 ns), fixed-amplitude pulses when their input signal exceeds a threshold of 100 mV. Discriminator 1 provides a single pulse for each scattered light pulse whose AC amplitude exceeds the threshold. This pulse is used to trigger a gate-and-reset generator. The gate-and-reset generator is the source of the synchronized pulses that activate the system for signal processing, reset it when the processing is complete, and ensure that only a single PMT pulse is selected for processing. It produces a gating pulse of 0.6  $\mu\text{s}$  and a reset pulse of 20  $\mu\text{s}$ . The 0.6  $\mu\text{s}$  pulse minimizes the chances that the system will act on two closely spaced pulses from the PMT. The 20  $\mu\text{s}$  pulse controls the hold time of the peak-sense-and-hold circuits and resets the system for the next PMT pulse to be examined. The generator cannot be triggered until the end of the reset pulse. The 20  $\mu\text{s}$  pulse length was required by the tape recorder used in the tests; it can be easily modified to accommodate the requirements



**Figure 9 – Schematic diagram of particle sizing instrumentation (PSI).**

of an A/D converter or other device. In principle, the reset time sets the system data rate at 50,000 particles/second, which is actually further reduced by the additional restriction (described below) that the particle pass through the center of the scattering volume.

The output of discriminator 2 is a train of narrow pulses equal to the number of fringes crossed by the particle or particles and is used as a second means of determining valid signals. A valid signal contains exactly 16 cycles of modulation on the signal produced by a particle crossing the 16 fringes in the center of the LDV scattering volume. Particles that are off center or are followed closely by a second particle will produce either more or less cycles of modulation during the 0.6  $\mu$ s gating period. The discriminator produces an output pulse for each cycle of modulation. All pulses have the same amplitude and their width is adjusted so that 16 pulses in the range of 30 to 80 MHz produce outputs of nearly equal amplitude from the gated ramp generator. The single channel analyzer (SCA) amplifies and shapes the ramp

voltage so that only a signal with 16 fringes will fall in the SCA selection window and produce an output pulse. It is this pulse that triggers the linear gated amplifier and allows the processed signal to be recorded. This restriction also ensures fairly uniform illumination for particles that are not too large (<100 to 150  $\mu$ m).

The SCA pulse, which is related to the time to the 16th cycle of modulation, also becomes a start trigger for the time-to-pulse-height converter (TPHC). The TPHC produces a 0 to 10 V output pulse having an amplitude that depends on the time difference between the start and stop pulses. The output of discriminator 1, which occurs at the start of the modulation, is delayed more than the actual length of the scattered pulse so that it can be used as a stop pulse. With this technique, the TPHC is activated only when valid signals are present; the faster particles produce signals of greater amplitude than the slower particles. The TPHC signal is also stretched and held for future recording.

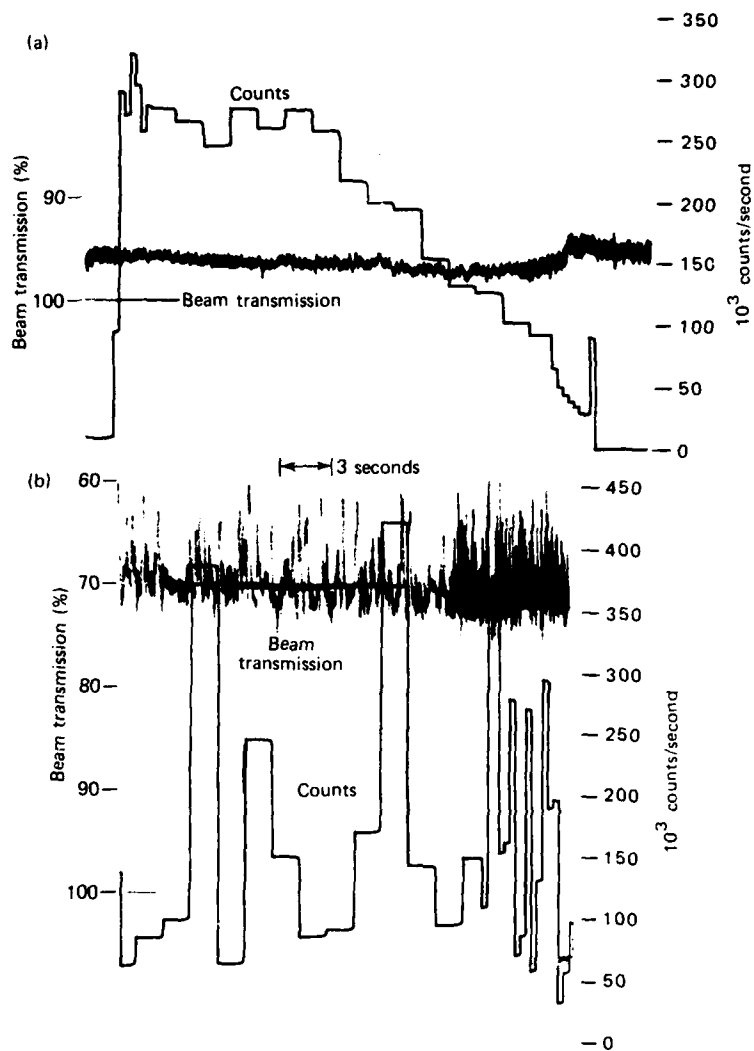
## 6. PARTICLE COUNT

In addition to the measurements of scattered intensity and particle visibility, the flux of particles greater than about 3  $\mu$ m in diameter is counted. The minimum sized particle counted is determined by the individual pulses that exceed the threshold of discriminator 1 and so is a function of laser power, PMT voltage, and particle density. The maximum count before pulse pile-up becomes a problem is about  $10^6$ . The average density of particles in the flow is computed from

$$n = \frac{N}{Av} \approx \frac{N}{440} \text{ (for high velocity flow),} \quad (11)$$

where  $n$  is the particle density (particles/cm<sup>3</sup>),  $N$  is the number of counts/second,  $v$  is the velocity in cm/s, and  $A$  is the LDA scattering area cross section ( $6.3 \times 10^{-3}$  cm<sup>2</sup>).

The output of discriminator 1 is used to trigger a photon counter (an Ortec 9315 digital counter used with an Ortec 9325 analog counter), allowing the count for 0.1 second to be recorded. For the tests described here, the count rate and the transmitted laser power were recorded together on a strip-chart recorder. An example of the recorded data is shown in Fig. 10. The section shown gives an idea of the large fluctuations in count rate that are sometimes observed - a point that is discussed in more detail later.



**Figure 10** - A representative sample of the particle-count measurement and the beam transmission measurement. The LDV was positioned 5.06 in. from the nozzle and the ER was 2.5. (a) Fuel/air mixture only; (b) Burning mixture.

## 7. BEAM TRANSMISSION

The integrated effects of particle density, size, and scattering path length attenuate the LDV laser beams. The attenuation of one of the laser beams was measured during the tests to indicate the total amount of material in the flow and to confirm qualitatively the particle sizing results determined by the visibility and intensity measurement.

The transmission ratio,  $I/I_0$ , where  $I$  is the measured intensity with particles present and  $I_0$  is the intensity when no particles are present, is the integrated result of particle density  $n$ , extinction efficiency  $Q_{ext}$ , particle cross section  $s$ , and the path length  $l$ , i.e.,

$$I/I_0 = \exp \int_0^l -n Q_{ext} s \, dl. \quad (12)$$

The  $Q_{ext}$  is very close to 2 for most of the particles of interest, and it probably averages more nearly 1 for the great number of smaller particles that contribute to the beam attenuation. Since this measurement is an average along the beam path through the flame, average values have been assumed and a  $Q_{ext} = 2$  has been assumed for all results quoted. The path length

was derived from photographs of the scattered laser beam.

After the LDV beam passed through the combustion zone it was chopped and deflected to a silicon *pin* diode (UDT-10DP) detector. The detector was covered with an adjustable iris and a 0.6328  $\mu\text{m}$  band-pass filter. The output of the detector was demodulated with a phase-locked detector and recorded together with the particle-counter output. The iris was set to its minimum opening of 2 mm for most measurements, ensuring that for the distance to the detector (600 mm) from the scatterers, the scattering from particles less than about 100  $\mu\text{m}$  would not be detected. As particle diameters become larger, more of the diffracted energy will be measured, with the result that their scattered light contribution would not be included in the attenuation measurement. Ideally, it would be desirable to monitor the instantaneous laser power and use it to normalize the transmitted signal, but time did not permit. Transmission measurements before and after the combustor tests indicated that there was no significant variation of the laser output during the runs.

## 8. COMBUSTOR MEASUREMENTS

A series of tests was made on the fuel-rich ramjet combustor<sup>30</sup>, in Test Cell 5 at the APL Propulsion Research Laboratory, on July 13, 14, and 15, 1982, to evaluate the suitability of the instrument for the intended application. All the data involving particle sizing were recorded on magnetic tape or a strip chart in the test cell and were synchronized with the combustor performance data recorded outside the test cell. A limited amount of the data was reduced manually to determine how the instrument and the combustor were performing. Measurements were made with the LDV scattering volume located on the centerline of the exhaust plume at selected distances from 0.25 to 9 in. from the combustor exit nozzle. Most of the measurements were made with the LDV collection optics positioned at an elevation angle (with respect to the plane of the LDV beams) of 5.8° - forward scattering. Limited measurements were also made at scattering angles of 90 to 160° to explore the effect of scattering angle on the visibility. The combustor was operated at a nominal pressure of 35 psia, an air inlet temperature of 650 to 870 K, and at fuel ER's of 2.6 and 1.6.

A typical run lasted 30 to 60 seconds during which particle sizing and velocity information were obtained on about 1000 particles. For the purposes of this evaluation only 50 to 55 points were reduced at each LDV position. The majority of the particles measured were larger than expected, and the size determinations were based mainly on the intensity of the scattered signal. The intensity signal was calibrated on the basis of those cases where good visibility information and intensity information were available from the same particle. The laboratory-derived calibration curve was used for the larger sized particles.

Table 1 lists the average values and the standard deviations of the particle size and velocity at selected distances from the nozzle for an ER of 2.6. Figure 11 contains plots of the average diameter, the average particle speed, and the negative log of the transmission ratio. The speed of the particles increases in the first two inches from the nozzle from 690 to 790 m/s,

Table 1 - Average values and the standard deviation of the particle size and velocity at selected distances from the nozzle (ER = 2.6).

Position from Nozzle Exit (cm)	Velocity		Diameter	
	Ave (m/s)	$\sigma$ (m/s)	Ave ( $\mu\text{m}$ )	$\sigma$ ( $\mu\text{m}$ )
0.64	690	86	53.7	40.1
1.27	703	99	67.0	38.1
2.54	739	103	61.7	37.9
5.08	780	114	62.0	34.2
7.6	716	131	44.2	30.5
10.2	677	100	53.0	33.4
12.7	<554	57	43.0	26.9
15.2	<528	—	50.4	31.7
17.8	<528	—	51.1	30.0
20.3	<528	—	74.7	38.1
22.9	<528	—	80.0	31.0

which is the region of the accelerating flow field. The particle speed then decreases monotonically with increasing distance from the nozzle to the minimum of 528 m/s that could be measured with the instrument during these tests. The particle diameter decreases with distance from the nozzle for the first five inches and then increases at greater distances downstream. The negative of the log of the transmission ratio increases linearly with distance for the first five inches and then remains constant as the distance increases. In general, the fluctuations of the transmitted signal increase with distance from the nozzle. Wide variations in the particle count were observed, particularly at the greater distances from the nozzle, but averaged around 100,000 counts/second at all positions.

Table 2 and Fig. 12 contain the same type of information and plots as Table 1 and Fig. 11 but for an ER of 1.6. The results are similar. The particle size again decreases and then increases with distance from the nozzle. The maximum velocity is slightly higher and does not drop off as rapidly. The transmission is about one-half that measured for an ER of 2.6. The particle count rate is approximately constant at 40,000 counts/second. These results are consistent with those derived from the higher ER value and are in the direction expected at the lower ER value.

<sup>30</sup> R. E. Lee, R. Turner, and F. S. Billig, "Particulate Measurements in the APL Fuel-Rich Ramjet-Combustor Supersonic Exhaust Flow," Proc. 1980 Fall Meeting of Western States Section The Combustion Institute, 20-21 Oct. 1980.

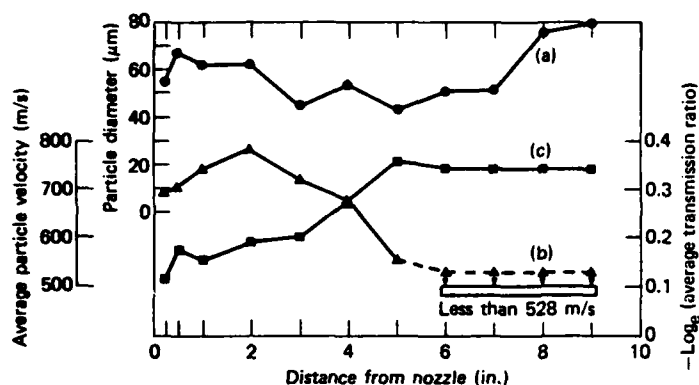


Figure 11 - The average values of the measured (a) diameter, (b) speed, and (c) negative log of the transmission ratio (turbidity), each plotted as a function of distance from the exhaust nozzle for an ER of 2.6.

Table 2 - Average values and the standard deviation of the particle size and velocity at selected distances from the nozzle (ER = 1.6).

Position from Nozzle Exit (cm)	Velocity		Diameter	
	Ave (m/s)	$\sigma$ (m/s)	Ave ( $\mu$ m)	$\sigma$ ( $\mu$ m)
0.64	619	98	49.5	25.9
1.27	715	159	53.1	31.0
2.54	779	157	58.9	36.1
5.08	819	150	62.1	38.5
7.6	747	164	57.9	37.6
10.2	741	156	57.0	35.7
12.7	694	170	39.1	25.4
15.2	43% < 528	—	44.6	29.2
17.8	69% < 528	—	54.3	34.3
20.3	74% < 528	—	65.5	39.2
22.9	67% < 528	—	69.7	36.7

Measurements were also made at both ER's for nonburning fuel/air mixtures. No detailed particle-size data were obtained because the particle speed (160 m/s) was below the minimum speed of the instrument. The data were obtained by photographing the PMT signals produced by individual particles. For the nonburning fuel/air mixture (ER = 2.4), the transmission ratio ( $I/I_0$ ) was 0.96; the particle count, 275,000 counts/second; the average speed, 160 m/s; and the estimated path length, 2 cm at the measurement position. For these conditions, the calculated particle density is 2750 particles/cm<sup>3</sup>. The average particle diameter is 22  $\mu$ m (assuming that the particles counted are the only particles present, that

there are no small particles, that the scattering path length is the same as that measured photographically in the burning case, and that  $Q_{ext} = 2$ ). The particle diameter derived from individual visibility measurements is 15 to 20  $\mu$ m. The agreement in size, as derived by the two methods, is good despite the fact that limited data were available; this agreement indicates that it is reasonable to assume that most of the particles (in this case) were large. The mass flow calculated from these results is more than 12% of the actual mass flow of the input fuel to the combustor. Similar calculations based on beam transmission measurements with a burning mixture (ER = 2.6) at a point 2 in. away from the nozzle give a particle density of 246 particles/cm<sup>3</sup> and an average particle size of 155  $\mu$ m. The diameter calculated from the transmission measurement is much greater than the 50  $\mu$ m diameter measured by the particle-sizing apparatus, indicating that a large fraction of the particle mass is carried by particles smaller than the 3  $\mu$ m sized particles that can be counted directly. It is expected that a large fraction of the burning or burnt particles will be small.

The measured decrease in particle size as distance from the nozzle increases appears to be real. However, because the small particles slow down faster than the large ones, and considering the shock structure involved and the transient nature of the flow, the density of small particles in the LDV measuring volume can be greater than the density of large particles. In this case, the size distribution will be skewed to the smaller particles, as was observed. On the other hand, if the measured particles are fuel droplets, it would be expected that some evaporation would take



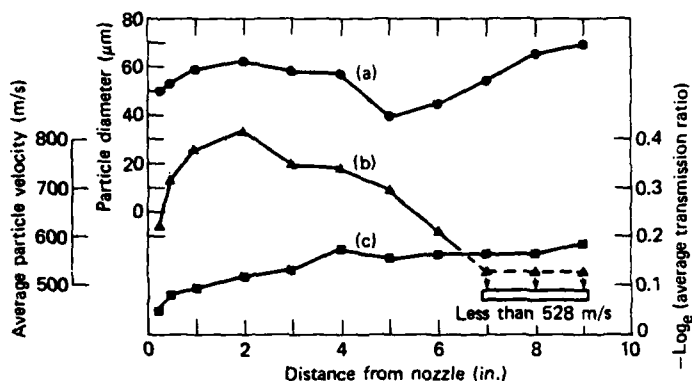


Figure 12 - The average values of the measured (a) diameter, (b) speed, and (c) negative log of the transmission ratios (turbidity), each plotted as a function of distance from the exhaust nozzle for an ER of 1.6.

place in the high temperature air as the distance downstream increases; hence smaller average particle diameter. The increase in particle diameter at distances greater than 5 in. from the nozzle is almost certainly an artifact. The slower small particles drop below the minimum speed for which their diameters can be measured before the faster large particles do, with the result that more large particles than small particles are measured.

The results obtained from the measurements at scattering angles of 90 and 160° were limited because

of the poor signal-to-noise ratio and the difficulty with LDV alignment, particularly at 90°. It was necessary in both cases either to remove the field-limiting aperture or to increase its diameter substantially, resulting in a particle count rate that was greater than could be handled by the PSI. A very limited sample of data at 160° for the fuel/air mixture gave a visibility measurement of 0.33 compared to a calculated value of 0.32 for a 48  $\mu\text{m}$  particle. Although these results may be just coincidental, they do show some promise.

## 9. CONCLUSIONS

Both laboratory measurements and measurements made under actual test conditions have shown that the output of a standard LDV can be used to provide simultaneous measurement of the diameter and velocity of individual particles in a supersonic flow. Procedures and computer programs have been developed to calibrate the instrument and to calculate its response function for a variety of operating conditions. This last requirement is quite important, particularly if other than small forward scattering angles are used.

The instrument used in the actual combustor test performed well. The size of the particles, however, was larger than was expected and the particles also moved more slowly than was expected. A much lower speed-gate limit would have been desirable for these tests. The larger-than-expected particle sizes (which were most likely unburnt fuel) meant that it was necessary to place greater reliance on the intensity measurement for particle sizing. The limited dynamic range of the visibility technique together with the multivalued condition requires a simultaneous intensity measurement in any actual combustor measurement.

There are still many points that must be considered before any measurement of this type can be accepted with confidence. The flame under study has a complicated shock structure for most of the region of measurement and contains a large number of small particles. The possibility that the coherence of the two LDV beams can be affected by the conditions in the flame must be considered. If the coherence is affected, there would be a reduction of the measured visibility and resultant distortion of the size measurement, but based on other reported LDV velocity measurements this does not appear to be a serious problem. However, any future measurement should include actual seeding of the flame with noncombustible particles of known sizes to establish that this is really the case and to provide a calibration of the instrument under actual operating conditions. The beam attenuation measurements indicated that multiple scattering was taking place, particularly downstream for the higher ER's. The attenuation measurement proved to be a useful complement to the PSI approach and it is thought to be appropriate that advantage be taken of such similar simple diagnostics in future measurements. This measurement is very sen-

sitive to refractive effects in the flame because of the small aperture required to extend the range of sizes of particles included in the measurement. Any future measurements should be comprehensive enough to establish whether refractive effects are playing any part. Data reduction should be automated; the present instrument can easily be modified so that on-line processing of much larger amounts of data can be handled by a minicomputer. The exigencies of the situation forced the use of an antiquated data-handling technology.

The results raise questions that could use help from other directions. Some of these questions include (a) "are the sizes measured consistent with the fuel injectors and combustion conditions?" and (b) "how good is the assumption that the large particles, assumed to be unburnt fuel are spherical?" All the analysis considered so far assumes spherical particles, but because of the high Weber numbers involved, distortion of, and even breakup of, the particles must be considered. Preliminary calculations using diffraction theory were made for a cylindrical particle with a length-to-diameter ratio ( $L/D$ ) of 3 to indicate the significance of distortion on particle size. A rough estimate is that for both the visibility and the intensity measurements, an overestimate of the particle size by a factor of about 2 would result if spherical particles were assumed when actually cylinders of equal volume with an  $L/D = 3$  were present. The possibility of distortion and breakup of liquid drops and the interpretation of the scattered light signals need further consideration. Another question to be considered is "How much evaporation should be expected for burning and nonburning flows?"

Additional measurements should be made to confirm the techniques that were used, both because in the backscattering region the visibility technique may be an effective way to measure the larger sized particles that seem to be present in the combustor and because of the ease (in many cases) of the actual physical placement of the instrument. Sufficient diagnostic techniques should be used to ensure that a reasonable accounting can be made for the total number of particles in the flow. A simple experiment using the diffraction pattern of the particle could be well employed to determine whether the particles are spherical or distorted spheres.

## ACKNOWLEDGMENTS

We would like to acknowledge the following people for their contributions to this work: R. E. Lee for letting us use the LDV, the aerosol generator, and the wind tunnel, and for his assistance during the operations in the test cell and on other occasions; S. Favin for his assistance with the computer programming phase; J. Funk, C. Stevens, J. Creeden, H. B. Land, and M. Rose for their help in conducting the test in Test Cell 5 and in assisting with the data reduction; R. C. Benson, B. H. Hochheimer, and R. A. Farrell of the Research Center for their timely help; and T. O. Poehler and F. S. Billig for their support.

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## APPENDIX A

### FORTRAN PROGRAM FOR CALCULATING THE VISIBILITY AND THE SCATTERED INTENSITY FOR A SPHERICAL PARTICLE, USING THE DIFFRACTION APPROXIMATION

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)  
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

```

C      PROGRAM CALCULATES THE VISIBILITY AND SCATTERED INTENSITY USING
C      THE DIFFRACTION APPROXIMATION FOR SPHERICAL PARTICLES.
C      SCALE FACTOR ALPHA
C      X(1)=PHI
C      X(2)=THETA
C      TMIN,TMAX,=MIN ANGLE RADS(THETA) AND MAX FOR COLLECTING APERTURE
C      A=APERTURE RADIUS(MM),Z=FOCAL LENGTH (MM)
C      APERTURE IS CENTERED IN XZ PLANE.
C      AL=ALPHA WHERE A=PARTICLE RADIUS (MICRONS)
C      GAMMA EQUALS ONE-HALF THE BEAM CROSSING ANGLE
C      EQUATION RELATING PHI AND THETA FOR THE APERTURE IS:
C      COS(PHI)=(A+Z*TMIN)**2-A**2+ (Z*THETA)**2/2*(A+Z*TMIN)*Z*THETA
C      THE EQUATION FOR THE RELATIONSHIP BETWEEN PHI AND THETA IS:
C      COS(PHI)=COS(A/Z)-COS(THETA)*COS(A/Z+TMIN)/SIN(THETA)*SIN(A/Z+TMIN)
C      IMPLICIT REAL*8(A-H,O-Z)
C      DIMENSION SP(30)
C      COMMON/INPUT/AL,WAVE,K,OUT
C      COMMON/LIMITS/ TMIN,TMAX,A,Z,C1,C2
C      COMMON/LOGCOM/ONCE
C      COMMON/DIAG/PHIM
C      LOGICAL ONCE
C      LOGICAL OUT
C      OUT=.FALSE.
C
C      READ(5,*,END=99) NSP
C      READ(5,*) (SP(I),I=1,NSP)
C      PRINT 3, NSP,(SP(I),I=1,NSP)
C      FORMAT (15/(10F10.3))
C      20 CONTINUE
C      PRINT 1
C      1 FORMAT('1')
C      READ(5,*,END=99) TMIN,TMAX,A,Z,WAVE
C      PHIM=0.000
C      ONCE=.FALSE.
C      C1=A/Z
C      C2=C1+TMIN
C      PRINT 9
C      9 FORMAT('0 TMIN, TMAX, A, Z, WAVE')
C      PRINT 5,TMIN,TMAX,A,Z,WAVE
C      FORMAT('0',1P6G14.6)
C      DO 10 LX=1,NSP
C      AL=SP(LX)
C      CALL ZMINT
C      10 CONTINUE
C      GO TO 20
C      99 STOP
C      END

```

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

INTERNAL STATEMENT NUMBERS

SYMBOL	INTERNAL STATEMENT NUMBERS
A	0005 0018 0021 0025
I	0012 0012 0013 0013 0013
K	0004 0018 0021 0025
Z	0005 0004 0028 0021 0025
AL	0005 0021 0022
C1	0005 0021 0022
C2	0005 0021 0022
LX	0027 0028
SP	0003 0012 0013 0028 0013 0027
NSP	0011 0012 0013 0010
OUT	0004 0009 0010
ONCE	0006 0008 0020
PHIM	0007 0019
IMAX	0005 0018 0025
IMIN	0005 0018 0022 0025
WAVE	0004 0018 0025
ZMINT	0029

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

LABEL DEFINED REFERENCES

LABEL	DEFINED	REFERENCES
1	0017	0016
3	0014	0013
5	0026	0025
9	0024	0023
10	0030	0027
20	0015	0031
99	0032	0011 0018

SIZE OF PROGRAM 000426 HEXADECIMAL BYTES

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A SF	C	R*8	000010	I F	C	R*8	000010	K	C	R*8	000028
AL S	C	R*8	000000	C1 SF	C	R*8	000020	C2 S	C	R*8	000014
SP SF	C	R*8	000010	NSP SF	C	R*8	000010	OUT S	C	R*8	000014
PHIM S	C	R*8	000000	IMAX SF	C	R*8	000008	IMIN SF	C	R*8	000000
ZMINT SF	XF	L*4	000000	IBCOM#	F	XF	000000	LDFO#	F	XF	000000

\*\*\*\*\*COMMON INFORMATION\*\*\*\*\*

NAME OF COMMON BLOCK \* INPUT\* SIZE OF BLOCK 000018 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
AL	R*8	000000	WAVE	R*8	000008	K	R*8	000010

NAME OF COMMON BLOCK \*LIMITS\* SIZE OF BLOCK 000030 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
IMIN	R*8	000000	IMAX	R*8	000008	A	R*8	000010
C1	R*8	000020	C2	R*8	000028			

NAME OF COMMON BLOCK \*LOGCOM\* SIZE OF BLOCK 000004 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
AL	R*8	000000	WAVE	R*8	000008	K	R*8	000010

[illegible][illegible][illegible]

**SOURCE STATEMENT LABELS**

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
20	15	0002D4	10	30	0003DC	99	32	0003F8

## COMPILER GENERATED LABELS

LABEL	ISN	ADDR
100000	1	00022C
100004	12	000296
100010	31	0003f2
LABEL	ISN	ADDR
100001	11	000238
100007	18	0002E8
LABEL	ISN	ADDR
100002	11	00024C
100008	18	0002FC
LABEL	ISN	ADDR
100003	12	000270
100009	28	0003BC

## FORMAT STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
3	14	000028	1	17	000035	9	24	00003A
						5	26	00006D

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODDL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT COSINT XREF NOALC NOANSF TERM IBM FLAG(1)

```
*STATISTICS* SOURCE STATEMENTS = 32, PROGRAM SIZE = 1062, SUBPROGRAM NAME = MAIN
```

#STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED



REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE L INECOUNT(60) SIZE(MAX) AUTOBBL(NONE)  
SOURCE EBCDIC NOLIST NOCHECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

```

ISN 0002      SUBROUTINE ZMINT
C
ISN 0003      IMPLICIT REAL*8(A-H,O-Z)
ISN 0004      DIMENSION I(2),ZZ(2)
ISN 0005      COMMON/INPUT/AL,WAVE,K,OUT
ISN 0006      EXTERNAL XLOW,XUPP,FUNEV
ISN 0007      LOGICAL OUT
ISN 0008      I(1)=1
ISN 0009      I(2)=1
ISN 0010      CC=1.0141358D-10
ISN 0011      DO 33 K=1,2
ISN 0012      OUT=.FALSE.
ISN 0013      Z=XMINT(3,2,1,XLOW,XUPP,FUNEV)
C
C      INCIDENT POWER IS THE ACTUAL LASER POWER,THE FACTOR OF2 RESULTING
C      FROM THE BEAM SPLITTING IS ACCOUNTED FOR IN THE INTEGRATION OVER
C      ONLY ONE-HALF THE APERTURE.
      ZZ(K)=CC*Z*(AL**4)
33 CONTINUE
ISN 0014      V=(ZZ(1)-ZZ(2))/(ZZ(1)+ZZ(2))
ISN 0015      PM=(ZZ(1)+ZZ(2))/2
ISN 0016      PRINT 1,ZZ(1),ZZ(2),PM
ISN 0017      1 FORMAT(10 COLLECTED POWER (P/1),MAX=' 1PG14.6,
ISN 0018      1, MIN=' 1PG14.6 , MEAN=' 1PG14.6 )
ISN 0019      PRINT 3,V
ISN 0020      3 FORMAT(10 VISIBILITY=' 1PG20.8)
ISN 0021      RETURN
ISN 0022      END
ISN 0023

```

\*\*\*\*\*

REFERENCE

CROSS

FORTRAN

\*\*\*\*\*

INTERNAL STATEMENT NUMBERS

SYMBOL	INTERNAL STATEMENT NUMBERS
I	0004 0008 0009 0013
K	0005 0011 0014
V	0016 0020
Z	0013 0014
AL	0005 0014
CC	0010 0014
PM	0017 0018
ZZ	0004 0014
OUT	0005 0007
WAVE	0005
XLOW	0006 0013
XUPP	0006 0013
FUNEV	0006 0013
XMINT	0003
ZMINT	0002

\*\*\*\*\*

REFERENCE

CROSS

FORTRAN

\*\*\*\*\*

LABEL DEFINED REFERENCES

LABEL	DEFINED	REFERENCES
1	0019	0018
3	0021	0020

\*\*\*\*\*  
L I S T I N G \*\*\*\*\*  
L A B E L   D E F I N E D   R E F E R E N C E S  
33   0015   0011

NAME TAG TYPE ADD. NAME TAG TYPE ADD. NAME TAG TYPE ADD. TYPE  
I SFA 1\*4 000138 K SF C 1\*4 000010 V SF R\*8 000110 Z SF R\*8 000118  
AL F C R\*8 000000 CC SF R\*8 000120 PM SF R\*8 000128 ZZ SF R\*8 000140  
OUT S C L\*4 000014 WAVE C R\*8 000000 XLOW A XF R\*8 000000 XUPP A XF R\*8 000000  
FUNEV A XF R\*8 000000 XMINT F XF R\*8 000000 ZMINT R\*8 000130 IBCOM# R\*8 000000

\*\*\*\*\* COMMON INFORMATION \*\*\*\*\*

NAME OF COMMON BLOCK \* INPUT\* SIZE OF BLOCK 000018 HEXADECIMAL BYTES

VAR. NAME TYPE REL. ADDR. VAR. NAME TYPE REL. ADDR. VAR. NAME TYPE REL. ADDR.  
AL R\*8 000000 WAVE R\*8 000008 NR K 1\*4 000010 OUT L\*4 000014

SOURCE STATEMENT LABELS

LABEL ISN ADDR  
33 15 000208

COMPILER GENERATED LABELS

LABEL ISN ADDR LABEL ISN ADDR LABEL ISN ADDR  
100001 2 000190 100002 12 0001B4 100003 16 000222

FORMAT STATEMENT LABELS

LABEL ISN ADDR LABEL ISN ADDR LABEL ISN ADDR  
1 19 000028 3 21 00006A

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSINT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 22, PROGRAM SIZE = 728, SUBPROGRAM NAME = ZMINT

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED

\*LEVEL 2.3.0 (JUNE 78)

OS/360 FORTRAN H EXTENDED

DATE 82.292/15.25.16

PAGE 1

REQUESTED OPTIONS: XREF,MAP,OPT=0,COSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)  
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

ISN 0002	C	FUNCTION XLOW (J, X)	FUNC 10
ISN 0003		IMPLICIT REAL*8(A-H,O-Z)	FUNC 20
ISN 0004		COMMON/LIMITS/ TMIN, TMAX, A, Z, C1, C2	FUNC 30
ISN 0005		XLOW=0.000	FUNC 40
ISN 0006		IF(J.EQ.1) XLOW=TMIN	FUNC 50
ISN 0008		IF(TMIN.LT. 0.000 ) XLOW=0.000	FUNC 60
ISN 0010		RETURN	FUNC 70
ISN 0011		END	FUNC 80
			FUNC 90

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

SYMBOL INTERNAL STATEMENT NUMBERS

A	0004
J	0002
X	0002
Z	0004
C1	0004
C2	0004
TMAX	0004
TMIN	0004
XLOW	0002
	0006
	0005
	0006
	0008

33

/ XLOW / SIZE OF PROGRAM 00012A HEXADECIMAL BYTES											
NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	C	R*8	NR	J	C	R*8	NR	X	C	R*8	NR
C1	C	R*8	NR	C2	C	R*8	NR	TMAX	C	R*8	NR
XLOW S								TMIN	F	C	
											000000

\*\*\*\*\* COMMON INFORMATION \*\*\*\*\*

NAME OF COMMON BLOCK \*LIMITS\* SIZE OF BLOCK 000030 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TMIN	R*8	000000	IMAX	R*8	000008	A	R*8	000010
C1	R*8	000020	C2	R*8	000028	Z	R*8	000018

COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	0000B8	100002	7	0000CE	100003	8	0000DA
100005	10	0000F2				100004	9	0000EA

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 10, PROGRAM SIZE = 298, SUBPROGRAM NAME = XLOW

\*LEVEL 2.3.0 (JUNE 78)

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

OS/360 FORTRAN H EXTENDED

DATE 82.292/15.25.16

PAGE 2

108K BYTES OF CORE NOT USED

REQUESTED OPTIONS: XREF, MAP, OPT=0, GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE (LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)  
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

```

      ISN 0002      FUNCTION XUPP (J, X)
      ISN 0003      IMPLICIT REAL*8(A-H, O-Z)
      ISN 0004      DIMENSION X(2)
      ISN 0005      COMMON/LOGCOM/ONCE
      ISN 0006      COMMON/LIMITS/ TMIN, TMAX, A, Z, C1, C2
      ISN 0007      LOGICAL ONCE
      ISN 0008      GO TO(1,2),J
      ISN 0009      XUPP=TMAX
      ISN 0010      RETURN
      ISN 0011      2 XUPP=0.000
      ISN 0012      IF ( TMIN .LT. 0.000 ) GO TO 30
      ISN 0014      IF (X(1).EQ.0.0) RETURN
      ISN 0016      XN=DCOS(C1)-DCOS(X(1))*DCOS(C2)
      ISN 0017      XD=DSIN(X(1))*DSIN(C2)
      ISN 0018      XUPP=DARCOS(XN/XD)
      ISN 0019      GO TO 40
      ISN 0020      30 XUPP=3.1415900
      ISN 0021      40 CONTINUE
      ISN 0022      IF (ONCE) GO TO 110
      ISN 0024      ONCE=.TRUE.
      ISN 0025      PRINT4, X(1), XUPP
      ISN 0026      4 FORMAT(1, XUPP=, 1PG20.8)
      ISN 0027      110 CONTINUE
      ISN 0028      RETURN
      ISN 0029      END
      FUNC 10
      FUNC 20
      FUNC 30
      FUNC 40
      FUNC 50
      FUNC 60
      FUNC 70
      FUNC 80
      FUNC 90
      FUNC 100
      FUNC 110
      FUNC 120
      FUNC 130
      FUNC 140
      FUNC 150
      FUNC 160
      FUNC 170
      FUNC 180
      FUNC 190
      FUNC 200
      FUNC 210
      FUNC 220
      FUNC 230
      FUNC 240
      FUNC 250
      FUNC 260

```

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

INTERNAL STATEMENT NUMBERS

SYMBOL	INTERNAL STATEMENT NUMBERS	CROSS REFERENCE
A	0006	
J	0002 0008	
X	0002 0004	0014 0016 0017 0025
Z	0006	
C1	0006 0016	
C2	0006 0016	0017
XD	0017 0018	
XN	0016 0018	
DCOS	0016 0016	0016
DSIN	0017 0017	
ONCE	0005 0007	0022 0024
TMAX	0006 0009	
TMIN	0006 0012	
XUPP	0002 0009	0011 0018 0020 0025
DARCOS	0018	

\*\*\*\*\*FORTRAN REFERENCES LISTING\*\*\*\*\*

REFERENCES

LABEL	DEFINED	REFERENCES
1	0009	0008
2	0011	0008
4	0026	0025
30	0020	0012

\*\*\*\*\*F O R T R A N C R O S S R E F E R E N C E L I S T I N G\*\*\*\*\*

LABEL DEFINED REFERENCES  
 110 0021 0019  
 110 0027 0022

/ XUPP / SIZE OF PROGRAM 0002F2 HEXADECIMAL BYTES

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	C	R*8	NR	J	F	I*4	0000BC	X	FA	XR	000000
C1	FA	C	R*8	C2	FA	C	R*8	XD	SFA	C	R*8
DCOS	F	XF	R*8	DSIN	F	XF	R*8	ONCE	S	C	L*4
1MIN	C	R*8	000000	XUPP	SF	R*8	0000D0	DARCOS	F	XF	R*8
								IBCOM#			000000
											000000

\*\*\*\*\* COMMON INFORMATION \*\*\*\*\*

NAME OF COMMON BLOCK \*LOGCOM\* SIZE OF BLOCK 000004 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL.	ADDR.	VAR. NAME	TYPE	REL.	ADDR.	VAR. NAME	TYPE	REL.	ADDR.
ONCE	L*4		000000								

NAME OF COMMON BLOCK \*LIMITS\* SIZE OF BLOCK 000030 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL.	ADDR.	VAR. NAME	TYPE	REL.	ADDR.	VAR. NAME	TYPE	REL.	ADDR.
1MIN	R*8	000000		TMAX	R*8	000008		A	R*8	000010	NR
C1	R*8	000020		C2	R*8	000028		Z	R*8	000018	NR

SOURCE STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
1	9	00015A	2	11	00016E	30	20	00025E
110	27	0002AC				40	21	000266

COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	000140	100003	14	000186	100004	15	000196
100006	24	000278				100005	16	00019E

FORMAT STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
4	26	000028						

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 28, PROGRAM SIZE = 754, SUBPROGRAM NAME = XUPP

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED

REQUESTED OPTIONS: XREF,MAP,OPI=0,COSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)  
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

```

ISN 0002      C      FUNCTION FUNEV(J,X)
ISN 0003      C      IMPLICIT REAL*8(A-H,O-Z)
ISN 0004      C      COMMON/INPUT/AL,WAVE,K
ISN 0005      C      DIMENSION X(2),I(2),M(2)
ISN 0006      C      GO TO (1,2),J
ISN 0007      C      1      FUNEV=1.000
ISN 0008      C      RETURN
ISN 0009      C      2      CALL BESE12 (X,W)
ISN 0010      C      FUNEV=W(K)*DSIN(X(1))
ISN 0011      C      RETURN
ISN 0012      C      END

```

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

SYMBOL INTERNAL STATEMENT NUMBERS

```

E      0005
J      0002 0006
K      0004 0010
W      0005 0009 0010
X      0002 0005 0009 0010
AL      0004
DSIN    0010
WAVE    0004
FUNEV   0002 0007 0010
BESE12  0009

```

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

LABEL DEFINED REFERENCES

```

1      0007 0006
2      0009 0006

```

				/ FUNEV /				SIZE OF PROGRAM 0001BC HEXADECIMAL BYTES			
NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
E	X SFA XR	R*8	NR	J	F	C	R*8	K	F	C	1*4
FUNEVS		R*8	0000000	AL	C	R*8	NR	DSIN	F	XF	R*8
			00000A0	BESE12	SF	XF	0000000	NR			0000000

\*\*\*\*\*COMMON INFORMATION\*\*\*\*\*

NAME OF COMMON BLOCK * INPUT*				SIZE OF BLOCK				0000114 HEXADECIMAL BYTES			
VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
AL	R*8	0000000	NR	R*8	0000008	WAVE	R*8	0000008	K	1*4	000010

DATE 82.292/15.25.17

OS/360 FORTRAN II EXTENDED

\*LEVEL 2.3.0 (JUNE 78)

LABEL ISN ADDR  
1 7 000112

LABEL ISN ADDR  
2 9 000122

LABEL ISN ADDR  
2 9 000122

COMPILER GENERATED LABELS

LABEL ISN ADDR  
100001 2 0000f8

LABEL ISN ADDR

LABEL ISN ADDR

LABEL ISN ADDR

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 11, PROGRAM SIZE = 144, SUBPROGRAM NAME = FUNEV

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED







```

ISN 0075      PRINT 17,X(1),X(2),ARG(1),AA,BJJ,ATETA,APHI,PHIM
ISN 0076      PRINT 18,ARG(2)
ISN 0077      17 FORMAT('0',1PG10,6)
ISN 0078      18 FORMAT(129,1PG10,6)
              C
              C
ISN 0079      35      RETURN
ISN 0080      END
    
```

SYMBOL	INTERNAL	STATEMENT	CROSS	REFERENCE	LISTING
		NUMBERS			G*****
I	0008	0056	0057	0058	0059
J	0029	0030	0031	0033	0034
K	0005	0031	0033	0034	0035
W	0002	0008	0058	0067	0067
X	0002	0008	0024	0025	0026
AA	0038	0039	0040	0042	0043
AL	0005	0038	0062		
E1	0010	0045	0056	0057	0057
E2	0010	0046	0056	0057	0057
FN	0006	0022	0067		
PI	0017	0018	0062		
ARG	0008	0034	0035	0037	0038
BJJ	0039	0030	0042	0045	0046
CX1	0025	0033	0044		
CX2	0027	0037	0064		
DEC	0018	0063			
DIA	0062	0067			
CAM	0019	0021			
GSC	0004	0004	0019	0020	0022
TER	0039				
OUT	0005	0013	0049	0059	0061
PHI	0011	0044	0045	0046	0071
PSI	0010	0037	0044	0056	0056
RAD	0006				
SGN	0030	0033	0053	0056	0057
SX1	0024	0033			
SX2	0026	0033			
APHI	0047	0047	0064	0075	
CCAM	0021	0033			
CSTH	0009	0033	0034		
DBJJ	0039				
DCOS	0021	0025	0027	0046	0056
DSIN	0024	0026	0037	0038	0045
DTAN	0044				
ONCL	0012	0014	0014	0016	
PHIM	0007	0047	0047	0075	
SGAM	0020	0033	0037		
SGN2	0028	0031	0053	0056	0057
WAVE	0005	0022	0062		
ATETA		0063	0075		
DAIAN	0017	0044			
BES12	0002				
DARCOS	0034				
DARSIN	0019	0037			

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

REFERENCES

LABEL	DEFINED	REFERENCES
1	0054	0053
3	0052	0051
5	0066	0065
7	0068	0067
9	0070	0069
13	0072	0071
17	0077	0075
18	0078	0076
21	0074	0073
35	0079	0059
45	0055	0029
110	0023	0014
		0049

SIZE OF PROGRAM 0000C HEXADECIMAL BYTES

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
E SF		R*8	000308	J SFA		1*4	000274	K		1*4	000010	W SF		R*8	000000
X FA XR		R*8	000000	AA SFA		R*8	000280	AL F		R*8	000000	E1 SF		R*8	000318
E2 SF		R*8	000328	FN SF		R*8	000008	PI SF		R*8	000288	ARG SFA		R*8	000338
BJ1 SFA		R*8	000290	CX1 SFA		R*8	000298	CX2 SFA		R*8	0002A0	DEG SF		R*8	0002A8
DIA SF		R*8	000280	GAM SFA		R*8	000368	GSC FA		R*8	000348	IER SFA		1*4	000278
OUT S		1*4	000014	PH1 SFA		R*8	0002C8	PS1 SFA		R*8	000378	RAD		R*8	NR
SGN SF		R*8	0002C0	SX1 SF		R*8	000388	SK2 SF		R*8	0002D0	API1 SF		R*8	0002D8
CCAM SF		R*8	000000	CSTH SFA		R*8	000000	ONCE S		1*4	00027C	DCOS F		R*8	000000
DSIN FA XF		R*8	0002E0	DTAN FA XF		R*8	0002F0	HAVE F		R*8	000008	PHIM SF		R*8	000000
SCAM SFA		R*8	0002E8	SGN2 SF		R*8	000300	DARCOS F		R*8	000000	ATETA SF		R*8	0002F8
DATAN F		R*8	000000	BESEL2		R*8	000300					DARSIN F		R*8	000000
IBCON#		1*4	000000												

\*\*\*\*\*COMMON INFORMATION\*\*\*\*\*

NAME OF COMMON BLOCK \* INPUT\* SIZE OF BLOCK 000018 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
AL	R*8	000300	WAVE	R*8	000008	K	1*4	000010	OUT	L*4	000014

NAME OF COMMON BLOCK \* PARM\* SIZE OF BLOCK 000010 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
RAD	R*8	000000 NR	FN	R*8	000008						

NAME OF COMMON BLOCK \* DIAG\* SIZE OF BLOCK 000008 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
PHIM	R*8	000000									

SOURCE STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
110	23	000504	45	55	000924	35	79	0000C0

COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	000464	100002	16	000472	100003	30	0005B0	200001	32	0005E4
100004	32	0005F2	100005	33	0005FC	100006	36	0006A8	100007	37	0006B8
100008	41	000770	100009	42	000778	100010	43	000784	100011	44	000790
100012	48	0008B6	100013	49	0008C2	100014	51	0008D4	100015	56	00093A
100016	51	0008B4									

FORMAT STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
3	52	000028	1	54	000060	5	66	00006C	7	68	00008C
9	70	0000CA	13	72	000116	21	74	000122	17	77	00018F
18	78	00019B									

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 79, PROGRAM SIZE = 3340, SUBPROGRAM NAME =BESEL2

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

\*STATISTICS\* NO DIAGNOSTICS THIS STEP

92K BYTES OF CORE NOT USED

0	1MIN.	TMAX.	A.	Z.	WAVE		
	3.400000-02	.170000		17.00000	250.0000		.632800
	XUPP=	.10846085					
	XUPP=	.65636487					
	ARG,	BJ1,	SGN,		SGN2		
	.105032	.360567	1.00000		1.00000		
	ARG,	BJ1,	SGN,		SGN2		
	.112907	.341515	-1.00000		1.00000		
FN	DIA	E(1),	E(2),			W(K),	K
	28.1269	3.02140	-.246931		.657225	.492919	1
	PSI(1),	PSI(2),	PHI(1),		PHI(2)		
	.100614	9.360120-02	.259338		.452418		
	X(1)	X(2)	ARG		AA	BJ1	ATETA
	.108461	.359364	.105032		1.69001	.341515	6.21435
			.112907				20.5900
	ARG,	BJ1,	SGN,		SGN2		PHIM
	.105032	.360567	1.00000		1.00000		
	ARG,	BJ1,	SGN,		SGN2		
	.112907	.341515	-1.00000		-1.00000		
FN	DIA	E(1),	E(2),			W(K),	K
	28.1269	3.02140	-7.073370-03		1.769520-02	3.631530-04	2
	PSI(1),	PSI(2),	PHI(1),		PHI(2)		
	.100614	9.360120-02	.259338		.452418		
	X(1)	X(2)	ARG		AA	BJ1	ATETA
	.108461	.359364	.105032		1.69001	.341515	6.21435
			.112907				20.5900
	ARG,	BJ1,	SGN,		SGN2		PHIM

COLLECTED POWER (P/1), MAX= 1.871840-08 MIN= 1.030620-11 MEAN= 9.364360-09

VISIBILITY= .99889942

1  
15.000

## APPENDIX B

### FORTRAN PROGRAM FOR CALCULATING THE VISIBILITY AND THE SCATTERED INTENSITY FOR A SPHERICAL PARTICLE, USING THE MIE THEORY CALCULATIONS



REQUESTED OPTIONS: XREF,MAP,OPT=0,COSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)  
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

```

C      MAIN DRIVER      12/23/81
C
C      MIE SCATTERING RESPONSE FOR A TWO BEAM LDV
C
C
C      PROGRAM CALCULATES THE VISIBILITY AND THE MEAN SCATTERED INTENSITY FMAIN 70
C      SPHERICAL PARTICLES USING THE SUPERMIDI CODE TO CALCULATE THE MIE FUMAIN 80
C
C      THE REFERENCE FOR SUPERMIDI IS GREHAN AND COUFEBET APPLIED OPTICS VOLMAIN 100
C      15 OCTOBER 1979,(3489) AND INTERNAL REPORT T11/GG/79/03/20.SUPERMIDIMAIN 110
C      BE USED WITH PARTICLES HAVING LARGE IMAGINARY INDICES OF REFRACTION. MAIN 120
C
C      PARAMETERS: INDEX OF REFRACTION( RI-COMPLEX-FIVE VALUES);SIZE PARAMMAIN 160
C      ALPHA(KA-SP-20 VALUES);WAVELENGTH(WAVE-MICRONS);FOCAL LENGTH OF LENSMAIN 170
C      RADIUS OF APERTURE(A-MM);TMIN(MIN.ANGLE OF APERTURE-RADS);TMAX(MAX.AMAIN 180
C      APERTURE-RADS).THE APERTURE IS THE LIMITING APERTURE IN THE DETECTIONMAIN 190
C      THE APERTURE IS CIRCULAR AND CENTERED IN THE XZ PLANE.
C      ANGLE THETA CAN BE VARIED FROM ZERO TO 180.
C      ALL VALUES OF THE INPUTS ARE IN FREE FORMAT
C      THE INDEX OF REFRACTION OF THE MEDIUM IS SET TO 1.0
C
C      IMPLICIT REAL*8(A-H,O-Z,S)
C      COMPLEX*16 RI(5), INOICE
C      COMPLEX*16 ELEC(1000), EMAG(1000)
C      DIMENSION SP(20)
C
C      COMMON/INPUT/AL,WAVE,K,OUT
C      COMMON/LIMITS/ TMIN,TMAX,A,Z,C1,C2
C      COMMON /COMU/ AIRIN, INDICE
C      COMMON /COM5/ ALPHA
C      COMMON/LOGCOM/ONCE
C      COMMON/DIAG/PHIM
C
C      LOGICAL ONCE
C      LOGICAL OUT
C      OUT=.FALSE.
C
C      PRINT 1, NRI
C      READ(5,*,END=99) NRI
C      IF(NRI.GT. 5) GO TO 99
C      DO 20 I=1,NRI
C      READ (5,*) R1, R2
C      IF(DABS(R1) .GT. 100.0) GO TO 99
C      IF(DABS(R2) .GT. 100.0) GO TO 99
C      RI(I) = DCMPLX(R1,R2)
C      20 CONTINUE

```

```

ISN 0027      PRINT 1, NRI, (RI(1), I=1, NRI)
ISN 0028      1 FORMAT(15/(F10.3, F10.6))
ISN 0029      2 FORMAT(15/(F10.3, F10.6))
ISN 0030      READ(5, *, END=99) NSP
ISN 0031      READ(5, *) (SP(1), I=1, NSP)
ISN 0032      3 FORMAT(15/(F10.3, F10.6))
ISN 0033      PRINT 3, NSP, (SP(1), I=1, NSP)
ISN 0034      1000 CONTINUE
ISN 0035      READ(5, *, END=99) TMIN, TMAX, A, Z, WAVE
ISN 0036      PHIN=0.000
ISN 0037      ONCE=.FALSE.
ISN 0038      C1=A/Z
ISN 0039      C2=C1+TMIN
ISN 0040      PRINT 9, TMIN, TMAX, A, Z, WAVE
ISN 0041      9 FORMAT(15/(F10.3, F10.6))
ISN 0042      PRINT 5, TMIN, TMAX, A, Z, WAVE
ISN 0043      FORMAT(15/(F10.3, F10.6))
ISN 0044      5
ISN 0045      C
ISN 0046      DO 10 LRI=1, NRI
ISN 0047      INDICE=RI(LRI)
ISN 0048      C
ISN 0049      DO 10 LX=1, NSP
ISN 0050      ALPHA=SP(LX)
ISN 0051      AL = ALPHA
ISN 0052      CALL MIEMAN(QEXT, QSCA, QABS, ELEC, EMAG, NCO)
ISN 0053      C
ISN 0054      C
ISN 0055      PRINT 7, ALPHA, INDICE, QEXT, QSCA, QABS
ISN 0056      7 FORMAT(1H1, 'MIE COEFFICIENTS FOR X = ', F10.2, ' REF. INDEX = ',
ISN 0057      + F7.3, F10.6, 1H1//5X, 'QEXT = ', F10.6, ' QSCA = ', F10.6,
ISN 0058      25X, 'QABS = ', F15.5)
ISN 0059      PRINT 8, (1, ELEC(1), EMAG(1), I=1, NCO)
ISN 0060      8 FORMAT(10, //, (5X, 15, 1P4G20.7))
ISN 0061      C
ISN 0062      C
ISN 0063      CALL ZMINT
ISN 0064      C
ISN 0065      ZMINT IS AN APL INTEGRATION ROUTINE(5.01.100) AND IS NORMALLY USED
ISN 0066      TO PROVIDE A 16 POINT GAUSSIAN QUADRATURE INTEGRATION.
ISN 0067      10 CONTINUE
ISN 0068      GO TO 1000
ISN 0069      99 STOP
ISN 0070      END

```

\*\*\*\*\* FORTRAN CROSS REFERENCE LISTING \*\*\*\*\*

SYMBOL	INTERNAL STATEMENT NUMBERS	CROSS REFERENCE	LISTING
A	0007 0035 0038 0042		
I	0019 0025 0027 0027 0031 0031 0031 0033 0033 0033 0052 0052 0052		
K	0006 0035 0038 0042		
Z	0007 0048		
AL	0006 0048		
C1	0007 0038 0039		

SYMBOL	INTERNAL STATEMENT NUMBERS
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14
15	15
16	16
17	17
18	18
19	19
20	20
21	21
22	22
23	23
24	24
25	25
26	26
27	27
28	28
29	29
30	30
31	31
32	32
33	33
34	34
35	35
36	36
37	37
38	38
39	39
40	40
41	41
42	42
43	43
44	44
45	45
46	46
47	47
48	48
49	49
50	50
51	51
52	52
53	53
54	54
55	55
56	56
57	57
58	58
59	59
60	60
61	61
62	62
63	63
64	64
65	65
66	66
67	67
68	68
69	69
70	70
71	71
72	72
73	73
74	74
75	75
76	76
77	77
78	78
79	79
80	80
81	81
82	82
83	83
84	84
85	85
86	86
87	87
88	88
89	89
90	90
91	91
92	92
93	93
94	94
95	95
96	96
97	97
98	98
99	99
100	100

SYMBOL	INTERNAL SYMBOL
C2	0007
L1X	0046
R1	0003
R1	0020
R2	0020
SP	0005
IRI	0044
WCO	0049
NRI	0015
NSP	0030
OUT	0006
DABS	0021
FFEC	0004
REAG	0004
ONCE	0010
PHUM	0011
QABS	0049
QEXT	0049
QSCA	0049
INAX	0007
TMIN	0007
WAVE	0006
ALIN	0008
ALPHA	0009
ZMIN	0054
COMPLX	0025
INDICE	0003
EMAN	0049

**LABEL**      **DEFINED**      **REFERENCES**

LABEL	DEFINED
1	0028
2	0029
3	0032
5	0043
7	0051
8	0053
9	0041
10	0055
20	0026
99	0057
1000	0034

NAME	TAG	TYPE	ADD.
A	SF	R#8	000010
AL	C	R#8	000000
R1	SF	C#16	000278
LRI	SF	I#4	000198
OUT	S	L#4	000014
PHIM	C	R#8	000000
THAX	SF	C#8	000008
NAME	TAG	TYPE	ADD.
I	SF	I#4	000190
C1	SF	R#8	000020
R1	SFA	R#8	0001A8
NCO	SFA	I#4	00019C
ELEC	SFA	C#16	0002C8
QAB	SFA	R#8	0001B8
TMIN	SF	R#8	0000UD
NAME	TAG	TYPE	ADD.
K	C	I#4	000028
C2	S	R#8	0001B0
R2	SFA	R#8	0001A0
NR1	SF	I#4	0001AD
EMAG	SFA	C#16	004148
QEXT	SFA	R#8	0001C0
WAVE	SF	R#8	000008
NAME	TAG	TYPE	ADD.
Z	SF	R#8	000018
XX	SF	I#4	000194
SP	SF	R#8	0001D0
NSP	SF	I#4	0001A4
OCSA	S	L#4	000000
QNCA	SFA	R#8	0001C8
AIRIN	C	R#8	0001NR

\*LEVEL 2.3.0 (JUNE 78) MAIN OS/360 FORTRAN II EXTENDED DATE 82.354/10.15.06 PAGE 4

ALPHA SF C R\*8 000000 ZMINT SF XF 000000 IBCOM# XF L\*4 000000 INDICE SF C C\*16 000008  
 LDFIO# F XF I\*4 000000 MIEMAN SF XF 000000

\*\*\*\*\* COMMON INFORMATION \*\*\*\*\*

NAME OF COMMON BLOCK \* INPUT\* SIZE OF BLOCK 000018 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
AL	R*8	000000	WAVE	R*8	000008	K	I*4	000010	OUT	L*4	000014

NAME OF COMMON BLOCK \*LIMITS\* SIZE OF BLOCK 000030 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TMIN	R*8	000000	TMAX	R*8	000008	A	R*8	000010	Z	R*8	000018
C1	R*8	000020	C2	R*8	000028						

NAME OF COMMON BLOCK \* COM#\* SIZE OF BLOCK 000018 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
AIRN	R*8	000000	INDICE	C*16	000008						

NAME OF COMMON BLOCK \* COM5\* SIZE OF BLOCK 000008 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
ALPHA	R*8	000000									

NAME OF COMMON BLOCK \*LOGCOM\* SIZE OF BLOCK 000004 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
ONCE	L*4	000000									

NAME OF COMMON BLOCK \* DIAG\* SIZE OF BLOCK 000008 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
PHIM	R*8	000000									

SOURCE STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
20	26	008134	10	55	0083FA	99	57	00842C

COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100000	1	008064	100002	16	00808C	100003	19	0080BA
100004	20	0080C2	100005	23	0080F8	100007	27	00814A
100010	30	008184	100011	30	008198	100013	31	0081E2
100016	35	008220	100017	35	008234	100019	47	008318
100020	52	0083A0	100021	52	0083EA	100023	56	008426

FORMAT STATEMENT LABELS

DATE 82.354/10.15.06

FORTRAN II EXTENDED

OS/360

MAIN

\*LEVEL 2.3.0 (JUNE 78)

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
1	28	000028	2	29	000036	3	32	000040
5	43	000080	7	51	00008C	8	53	0000F2

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 57, PROGRAM SIZE = 33886, SUBPROGRAM NAME = MAIN

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

10MK BYTES OF CORE NOT USED

REQUESTED OPTIONS: XREF,MAP,OPT=0,COSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)  
SOURCE EBCDIC NOLIST NODDICK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

ISN 0002	C	SUBROUTINE MIEMAN(QEXT, QSCAT, QABS, ELEC, EMAG, LI)	MIEM 10
ISN 0003	C	IMPLICIT REAL*8(A-Z)	MIEM 20
ISN 0004		COMPLEX*16 EPER, EHOZ1, EHOZ2, EHOZ, ELEC(1000), EMAG(1000), BB, DD, BETA	MIEM 30
		1, INDICE	MIEM 40
ISN 0005	C	COMMON/COM1/B(1001)/COM2/NE(1001)/COM3/BETA/COM4/AIRIN, INDICE/	MIEM 50
ISN 0006	C	1COM5/ALPHA	MIEM 60
		COMMON/COM7/ X1,X2,Y1,Y2,XX	MIEM 70
ISN 0007	C	INTEGER J,L,N,IA,IB,JI,JJ,LL,IJKL	MIEM 80
ISN 0008		DIMENSION PO(1000),PA(1000)	MIEM 90
ISN 0009	C	DIMENSION W(2)	MIEM 100
		AIRIN=1.000	MIEM 110
ISN 0010	C		MIEM 120
ISN 0011		DO 8521 IJKL=1,1000	MIEM 130
ISN 0012		B(IJKL)=0.00+00	MIEM 140
ISN 0013		NE(IJKL)=0.00+00	MIEM 150
ISN 0014		ELEC(IJKL)={0.00+00,0.00+00}	MIEM 160
ISN 0015		EMAG(IJKL)={0.00+00,0.00+00}	MIEM 170
ISN 0016	8521	CONTINUE	MIEM 180
	C		MIEM 190
	C		MIEM 200
ISN 0017	C	PI=4*DATAN(1.000)	MIEM 210
ISN 0018		BETA=INDICE*ALPHA/AIRIN	MIEM 220
ISN 0019		L=IF IX(SNGL(ALPHA))	MIEM 230
ISN 0020		J=2*L	MIEM 240
		IF(J.GT.15) GO TO 1234	MIEM 250
	C		MIEM 260
	C		MIEM 270
	C		MIEM 280
	C		MIEM 290
	C		MIEM 300
	C		MIEM 310
	C		MIEM 320
	C		MIEM 330
	C		MIEM 340
	C		MIEM 350
	C		MIEM 360
	C		MIEM 370
	C		MIEM 380
	C		MIEM 390
	C		MIEM 400
ISN 0022		J=15	MIEM 410
ISN 0023	1234	JJ=J+1	MIEM 420
	C		MIEM 430
ISN 0024		CALL BESSEL(JJ,B,IA)	MIEM 440
ISN 0025		JJ=IA	MIEM 450
ISN 0026	C		MIEM 460
	C		MIEM 470
ISN 0027		CALL NEUMAN(JJ,NE,IB)	MIEM 480
	C		MIEM 490
	C		MIEM 500
ISN 0028		CALL VIBRA(ELEC,EMAG,J,LL)	MIEM 510
	C		MIEM 520
ISN 0029	37	QSCAT=0.000	MIEM 530

CALL FOR SUBROUTINES VIBRA, BESSEL, NEUMAN.

VIBRA, BESSEL, NEUMAN ARE SUPERMIDI ROUTINES.

```

ISN 0030      QEXT=0.000
ISN 0031      DO 59 N=1,LL
ISN 0032      RA=DREAL(ELC(N))
ISN 0033      RB=DREAL(EMAG(N))
ISN 0034      CA=ELC(N)*DCONJG(ELC(N))
ISN 0035      CB=EMAG(N)*DCONJG(EMAG(N))
ISN 0036      RCOEF=2.000**N+1.000
ISN 0037      QSCAT=QSCAT+RCOEF*(CA*CB)
ISN 0038      QEXT=QEXT+RCOEF*(RA*RB)
ISN 0039      59 CONTINUE
ISN 0040      RCO = 2.000/(ALPHA**2)
ISN 0041      QEXT = QEXT*RCO
ISN 0042      QSCAT = RCO*QSCAT
ISN 0043      QABS = QEXT-QSCAT
C
C
ISN 0044      RETURN
C
ISN 0045      W(1) IS THETA AND W(2) IS PHI
ENTRY MIECXU(W,EPER,EHOZ,DELT)
MIECXU IS A SUPERMIDI ROUTINE.
C
C
ISN 0046      TETA = W(1)
C
C
ISN 0047      EPER1=(0.000,0.000)
ISN 0048      EHOZ1=(0.000,0.000)
C
C
ISN 0049      CALL POLY(J,PO,PA,TETA)
POLY IS A SUPERMIDI ROUTINE.
C
C
ISN 0050      DO 5 N=1,LL
ISN 0051      X=N
ISN 0052      EPER=EPER1
ISN 0053      EHOZ=EHOZ1
ISN 0054      CC=PO(N)
ISN 0055      EE=PA(N)
ISN 0056      RD=ELEC(N)
ISN 0057      DD=EMAG(N)
ISN 0058      HH=(2.000**X+1.000)/(X*(X+1.000))
ISN 0059      EPER1=EPER+HH*(BB*CC+DD*EE)
ISN 0060      EHOZ1=EHOZ+HH*(BB*EE+DD*CC)
C
ISN 0061      5 CONTINUE
C
ISN 0062      X1=DREAL(EPER1)
ISN 0063      X2=DREAL(EHOZ1)
ISN 0064      Y1=DIMAG(EPER1)
ISN 0065      Y2=DIMAG(EHOZ1)
ISN 0066      XX=(X1*Y2-X2*Y1)/(X1*X2+Y1*Y2)
ISN 0067      DELT=DATAN(XX)

```

DELT IS THE PHASE DIFFERENCE BETWEEN THE PERPENDICULAR AND

PARALLEL COMPONENTS OF THE ELLIPTICALLY POLARIZED SCAT.LIGHT (RADS)

ISN 0068 RETURN  
ISN 0069 END

\*\*\*\*\* F O R T R A N C R O S S R E F E R E N C E L I S T I N G \*\*\*\*\*

SYMBOL	INTERNAL STATEMENT NUMBERS	CROSS REFERENCE
B	0005 0012 0024	
J	0007 0019 0020 0022 0023 0027 0028 0049	
L	0007 0018 0019	
N	0007 0031 0032 0033 0034 0035 0036 0050 0051 0054 0055 0056 0057	
W	0009 0045 0046	
X	0051 0058 0058 0058	
BB	0004 0056 0059 0060	
CA	0034 0037	
CB	0035 0037	
CC	0054 0059 0060	
DD	0004 0057 0059 0060	
FE	0055 0059 0060	
JH	0058 0059 0060	
IA	0007 0024 0025	
IB	0007 0026 0027	
JJ	0007 0023 0024 0025 0026 0031 0050	
LL	0002 0007 0028 0031 0050	
NE	0005 0013 0026	
PA	0008 0049 0055	
PO	0008 0049 0054	
RA	0032 0038	
RB	0033 0038	
XX	0006 0066 0066 0066	
X1	0006 0062 0066 0066	
X2	0006 0063 0066 0066	
Y1	0006 0064 0066 0066	
Y2	0006 0065 0066 0066	
RCO	0010 0041 0042	
BETA	0004 0005 0017	
DEL	0004 0067	
HOZ	0004 0045 0053 0060	
FLC	0002 0004 0014 0028 0032 0034 0034 0056	
FMAG	0002 0004 0015 0028 0033 0035 0035 0057	
EPER	0004 0045 0052 0059	
FIX	0018	
IJKL	0007 0011 0012 0013 0014 0015	
POLY	0049	
QABS	0002 0043	
QEXT	0002 0030 0038 0038 0041 0041 0043	
SNGL	0018	
TETA	0046 0049	
AIRIN	0005 0010 0017	
ALPHA	0005 0017 0018 0040	
DATAN	0067	
DMAG	0064 0065	
DREAL	0032 0033 0062 0063 0060 0063 0065	
HOZ1	0004 0048 0053 0060	



\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

SYMBOL	INTERNAL STATEMENT NUMBERS
EPER1	0004 0047 0052 0059 0062 0064
QSCAT	0002 0029 0037 0042 0043
RCOEI	0036 0037 0038
VIBRA	0028
BESSEL	0024
DCONJC	0034 0035 0017
INDICE	0004 0005
MTECXU	0045
MILMAN	0002
NEUMAN	0026

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

LABEL	DEFINED	REFERENCES
5	0061	0050
37	0029	
59	0039	0031
1234	0023	0020
8521	0016	0011

SIZE OF PROGRAM 004818 HEXADECIMAL BYTES

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
B SFA	C	R*8	000000	J SFA	I*4	R*8	000160	N SFA	I*4	R*8	000168
W F XR	R*8	R*8	000000	X SF	R*8	R*8	000180	CA SF	R*8	R*8	000188
CB SF	R*8	R*8	000190	CC SF	R*8	R*8	000198	EE SF	R*8	R*8	0001A0
III SF	R*8	R*8	0001A8	IA SFA	I*4	R*8	00016C	J1	I*4	R*8	NR
JJ SFA	I*4	R*8	000174	LI SFA	I*4	R*8	000178	NE SFA	C	R*8	000270
PO SFA	R*8	R*8	0002B0	RA SF	R*8	R*8	000180	RB SF	R*8	R*8	000200
X1 SF	C	R*8	000000	X2 SF	C	R*8	000008	Y1 SF	C	R*8	000018
RCO SF	R*8	R*8	0001C0	BFTA S	C	R*8	000000	DELT S	R*8	R*8	000230
ELEC SFA XR	C*16	R*8	000000	EMAG SFA XR	C	R*8	000000	EPER SF	C*16	R*8	00017C
POLY SF XF	R*8	R*8	000000	QABS S	R*8	R*8	0001D0	QEXT SF	R*8	R*8	0001E0
AIRIN SF C	R*8	R*8	000000	ALPHA FA C	R*8	R*8	000000	DATAN F XF	R*8	R*8	000250
EPER1 SFA	C*16	R*8	000260	QSCAT SF	R*8	R*8	0001E8	RCOEI SF XF	R*8	R*8	000000
CDDVD#	C*16	R*8	000000	CDMPY#	XF	R*8	000000	BESSEL SF XF	C*16	R*8	000008
MTECXU	R*8	R*8	0001F8	MILMAN	R*8	R*8	000200	NEUMAN SF XF	C	C*16	000008

\*\*\*\*\*COMMON INFORMATION\*\*\*\*\*

NAME OF COMMON BLOCK \* COM1\* SIZE OF BLOCK 001F48 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
B	R*8	000000						

NAME OF COMMON BLOCK \* COM2\* SIZE OF BLOCK 001F48 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NE	R*8	000000						

NAME OF COMMON BLOCK \* COM3\* SIZE OF BLOCK 000010 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.

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VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
BETA	C*16	000000						
NAME OF COMMON BLOCK * COM4* SIZE OF BLOCK 000018 HEXADECIMAL BYTES								
AIRIN	R*8	000000	INDEX	C*16	000008			
NAME OF COMMON BLOCK * COM5* SIZE OF BLOCK 000008 HEXADECIMAL BYTES								
ALPHA	R*8	000000						
NAME OF COMMON BLOCK * COM7* SIZE OF BLOCK 000028 HEXADECIMAL BYTES								
X1	R*8	000000	X2	R*8	000008	Y1	R*8	000010
XX	R*8	000020				Y2	R*8	000018

# SOURCE STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
8521	16	00421C	1234	23	0042D6	37	29	004320 NR
5	61	004706				59	39	004474

# COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	0041A8	100002	12	0041BC	100003	17	004232
100005	32	004334	100006	40	00448A	100007	45	000000
100009	51	00450E	100010	62	00471C	100008	45	0044CC

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 68, PROGRAM SIZE = 18680, SUBPROGRAM NAME =MIEMAN

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

96K BYTES OF CORE NOT USED

REQUESTED OPTIONS: XREF,MAP,OPT=0,COSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODRL(NONE)  
SOURCE EBCDIC NOLIST NODLCK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

```

ISN 0002      C      SUBROUTINE ZMINT
ISN 0003      IMPLICIT REAL*8(A-H,O-Z)
ISN 0004      DIMENSION I(2),ZZ(2)
ISN 0005      COMMON/INPUT/AL,WAVE,K,OUT
ISN 0006      EXTERNAL XLOW,XUPP,FUNEV
ISN 0007      LOGICAL OUT
ISN 0008      I(1)=1
ISN 0009      I(2)=1
ISN 0010      CC=1.0141358D-10
ISN 0011      DO 33 K=1,2
ISN 0012      OUT=.FALSE.
ISN 0013      C      Z=XMINT(3,2,1,XLOW,XUPP,FUNEV)
ISN 0014      C
ISN 0015      C      INCIDENT POWER IS THE ACTUAL LASER POWER, THE FACTOR OF 2 RESULTING
ISN 0016      C      FROM THE BEAM SPLITTING IS ACCOUNTED FOR IN THE INTEGRATION OVER
ISN 0017      C      ONLY ONE-HALF THE APERTURE.
ISN 0018      C      ZZ(K)=CC*Z
ISN 0019      C      33 CONTINUE
ISN 0020      V=(ZZ(1)-ZZ(2))/(ZZ(1)+ZZ(2))
ISN 0021      PM=(ZZ(1)+ZZ(2))/2
ISN 0022      PRINT 1,ZZ(1),ZZ(2),PM
ISN 0023      1  FORMAT('O COLLECTED POWER (P/I),MAX=',1PG14.6,
           1  ' MIN=',1PG14.6,
           1  ' MEAN=',1PG14.6,
           1  ' )
           3  PRINT 3,V
           3  FORMAT('O VISIBILITY=',1PG20.8)
           3  RETURN
           3  END

```

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

SYMBOL	INTERNAL STATEMENT NUMBERS	CROSS REFERENCE
I	0004 0008 0009 0013	
K	0005 0011 0014	
V	0016 0020	
Z	0013 0014	
AL	0005 0014	
CC	0010 0018	
PM	0017 0018	
ZZ	0004 0014 0016 0017 0018 0018 0018	
OUT	0005 0007	
WAVE	0012	
XLOW	0005 0013	
XUPP	0006 0013	
FUNEV	0006 0013	
XMINT	0013 0002	

\*\*\*\*\*I O R T R A N C R O S S R E F E R E N C E L I S T I N G\*\*\*\*\*

LABEL DEFINED REFERENCES

1 0019 0018  
3 0021 0020  
33 0015 0011

/ ZMINT / SIZE OF PROGRAM 0002C4 HEXADECIMAL BYTES

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
I SFA	C	R*8	NR	K SF	C	I*4	000010	V SF	R*8	R*8	000110	Z SF	R*8	R*8	000118
AL	C	R*8	NR	CC SF	C	R*8	000120	PM SF	R*8	R*8	000128	ZZ SF	R*8	R*8	000148
OUT	C	L*4	000014	OUT S	C	R*8	000130	WAVE	C	R*8	NR	XLOW	A XF	R*8	000000
XUPP	A XF	R*8	000000	FUNEV	A XF	R*8	000000	XMINT	F XF	R*8	000000	ZMINT	R*8	R*8	000138
IBCOM#	XF	I*4	000000												

\*\*\*\*\* COMMON INFORMATION \*\*\*\*\*

NAME OF COMMON BLOCK \* INPUT\* SIZE OF BLOCK 000018 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
AL	R*8	000000 NR	WAVE	R*8	000008 NR	K	I*4	000010

SOURCE STATEMENT LABELS

LABEL ISN ADDR  
33 15 0001F6

COMPILER GENERATED LABELS

LABEL ISN ADDR  
100001 2 000190

FORMAT STATEMENT LABELS

LABEL ISN ADDR  
1 19 000028

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 22, PROGRAM SIZE = 708, SUBPROGRAM NAME = ZMINT

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED

REQUESTED OPTIONS: XREF,MAP,OPT=0,COSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)  
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

```

ISN 0002      FUNCTION XLOW (J, X)
ISN 0003      IMPLICIT REAL*8(A-H,O-Z)
ISN 0004      COMMON/LIMITS/ TMIN,TMAX,A,Z,C1,C2
ISN 0005      XLOW=0.000
ISN 0006      IF(J.EQ.1) XLOW=TMIN
ISN 0008      IF(TMIN.LT. 0.000 ) XLOW=0.000
ISN 0010      RETURN
ISN 0011      END

```

\*\*\*\*\* FORTRAN CROSS REFERENCE LISTING \*\*\*\*\*

SYMBOL INTERNAL STATEMENT NUMBERS

```

A 0004
J 0002 0006
X 0002
Z 0004
C1 0004
C2 0004
TMAX 0004
TMIN 0004 0006 0008
XLOW 0002 0005 0006 0008

```

/ XLOW / SIZE OF PROGRAM 00012A HEXADECIMAL BYTES

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	C	R*8	NR	J	C	R*8	NR	TMIN	F	C	NR
C1	C	R*8	NR	C2	C	R*8	NR	TMAX	F	C	NR
XLOW	S	R*8	000090								

\*\*\*\*\* COMMON INFORMATION \*\*\*\*\*

NAME OF COMMON BLOCK \*LIMITS\* SIZE OF BLOCK 000030 HEXADECIMAL BYTES

VAR.	NAME	TYPE	REL.	ADDR.	VAR.	NAME	TYPE	REL.	ADDR.	VAR.	NAME	TYPE	REL.	ADDR.
TMIN	R*8	000000			TMAX	R*8	000008	NR						
C1	R*8	000020	NR		C2	R*8	000028	NR						

COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	0000B8	100002	7	0000CE	100003	8	0000DA
100005	10	0000F2				100004	9	0000EA

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 10, PROGRAM SIZE = 298, SUBPROGRAM NAME = XLOW

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*LEVEL 2.3.0 (JUNE 78)  
\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

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108K BYTES OF CORE NOT USED

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODR1(NONE)  
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOTFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

```

ISN 0002      FUNCTION XUPP (J, X)
ISN 0003      IMPLICIT REAL*8(A-H,O-Z)
ISN 0004      DIMENSION X(2)
ISN 0005      COMMON/LOGCOM/ONCE
ISN 0006      COMMON/LIMITS/ TMIN,IMAX,A,Z,C1,C2
ISN 0007      LOGICAL ONCE
ISN 0008      GO TO(1,2),J
ISN 0009      XUPP=IMAX
ISN 0010      RETURN
ISN 0011      2 XUPP=0.000
ISN 0012      IF ( TMIN .LT. 0.000 ) GOTO 30
ISN 0013      IF (X(1).EQ.0.0) RETURN
ISN 0014      XN=DCOS(C1)-DCOS(X(1))*DCOS(C2)
ISN 0015      XD=DSIN(X(1))*DSIN(C2)
ISN 0016      XUPP=DARCOS(XN/XD)
ISN 0017      GOTO 40
ISN 0018      30 XUPP=3.1415900
ISN 0019      40 CONTINUE
ISN 0020      IF (ONCE) GOTO 110
ISN 0021      ONCE= .TRUE.
ISN 0022      PRINT4,X(1),XUPP
ISN 0023      4 FORMAT(1X,UPP=,1PG20.8)
ISN 0024      110 CONTINUE
ISN 0025      RETURN
ISN 0026      END

```

\*\*\*\*\* F O R T R A N C R O S S R E F E R E N C E L I S T I N G \*\*\*\*\*

INTERNAL STATEMENT NUMBERS

SYMBOL	INTERNAL STATEMENT NUMBERS
A	0006
J	0002 0008
X	0002 0004 0014 0016 0017 0025
Z	0006
C1	0006 0016
C2	0006 0016 0017
XD	0017 0018
XN	0016 0018
DCOS	0016 0016 0016
DSIN	0017 0017
ONCE	0005 0007 0022 0024
TMAX	0006 0009
TMIN	0006 0012
XUPP	0002 0009 0011 0018 0020 0025
DARCOS	0018

\*\*\*\*\* F O R T R A N C R O S S R E F E R E N C E L I S T I N G \*\*\*\*\*

REFERENCES

LABEL	DEFINED	REFERENCES
1	0009	0008
2	0011	0008
4	0026	0025
30	0020	0012
40	0021	0019

\*\*\*\*\*F O R T R A N C R O S S R E F E R E N C E L I S T I N G\*\*\*\*\*  
 LABEL DEFINED REFERENCES  
 110 0027 0022

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	C	R*8	NR	J	F	I*4	0000BC	X	FA	XR	R*8	000000	Z	XN	SFA
C1	FA	C	000020	C2	FA	C	000028	XD	SFA	C	R*8	0000CO	TMAX	F	C
DCOS	F	XF	000000	DSIN	F	XF	000000	ONCE	S	C	L*4	000000	IBCOM#	F	XF
TMIN	C	R*8	000000	XUPP	SF	R*8	000000	DARCO	S	XF	R*8	000000			

## \*\*\*\*\* COMMON INFORMATION \*\*\*\*\*

NAME OF COMMON BLOCK \*LOGCOM\* SIZE OF BLOCK 000004 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
ONCE	L*4	000000						

NAME OF COMMON BLOCK \*LIMITS\* SIZE OF BLOCK 000030 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TMIN	R*8	000000	TMAX	R*8	000008	A	R*8	000010 NR
C1	R*8	000020	C2	R*8	000028	Z	R*8	000018 NR

## SOURCE STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
1	9	00015A	2	11	00016E	30	20	00025E
110	27	0002AC				40	21	000266

## COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	000140	100004	15	000196	100005	16	00019E
100006	24	000278						

## FORMAT STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
4	26	000028						

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 28, PROGRAM SIZE = 754, SUBPROGRAM NAME = XUPP

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED



REQUESTED OPTIONS: XREF,MAP,OPT=0,COSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTOOBL(NONE)  
SOURCE FBDDIC NOTIST NODICK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IDB FLAG(1)

```

ISN 0002      FUNCTION FUNEV(J,X)
ISN 0003      IMPLICIT REAL*8(A-H,O-Z)
ISN 0004      COMMON/INPUT/AL,WAVE,K
ISN 0005      DIMENSION X(2),E(2),W(2)
ISN 0006      GO TO (1,2),J
ISN 0007      1  FUNEV=1.000
ISN 0008      RETURN
ISN 0009      2  CONTINUE
ISN 0010      CALL BESEL3(X,W)
ISN 0011      FUNEV=W(K)*DSIN(X(1))
ISN 0012      RETURN
ISN 0013      END

```

\*\*\*\*\* F O R T R A N C R O S S R E F E R E N C E L I S T I N G \*\*\*\*\*

SYMBOL INTERNAL STATEMENT NUMBERS

```

E 0005
J 0002 0006
K 0004 0011
W 0005 0010 0011
X 0002 0005 0010 0011
AL 0004
DSIN 0011
WAVE 0004
FUNEV 0002 0007 0011
BESEL3 0010

```

\*\*\*\*\* F O R T R A N C R O S S R E F E R E N C E L I S T I N G \*\*\*\*\*

LABEL DEFINED REFERENCES

```

1 0007 0006
2 0009 0006

```

/ FUNEV / SIZE OF PROGRAM 0001BC HEXADECIMAL BYTES

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
E	R*8	R*8	NR	J	F	C	1*4	K	F	C	1*4
X SFA	XR	R*8	000000	AL	C	R*8	NR	DSIN	F	XF	R*8
FUNEV S	R*8	R*8	0000A0	BESEL3	SF	XF	000000	NR			

\*\*\*\*\* COMMON INFORMATION \*\*\*\*\*

NAME OF COMMON BLOCK \* INPUT\* SIZE OF BLOCK 000014 HEXADECIMAL BYTES

VAR.	NAME	TYPE	REL.	ADDR.	VAR.	NAME	TYPE	REL.	ADDR.	VAR.	NAME	TYPE	REL.	ADDR.
AL	R*8	R*8	000000	NR	WAVE	R*8	R*8	000008	NR	K	1*4	000010		

SOURCE STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
1	7	000112	2	9	000122			

COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	0000F8						

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTOOBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSIMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 12, PROGRAM SIZE = 444, SUBPROGRAM NAME = FUNEV

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSIMI

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(C SIZE(MAX) AUTODBL(NONE)  
SOURCE FBCDIC NO LIST NODECK OBJEC. 4AP NOFORMAT GOSIMI XREF NOALC NOANSF TERM IBM FLAG(1)

```

ISN 0002      SUBROUTINE BESE13(X,W)
C
C   THE LDV INPUT BEAM IS POLARIZED PARALLEL TO THE OX AXIS(VERTICAL)
C
C   GAMMA IS ONE-HALF THE TOTAL ANGLE OF SEPARATION OF THE TWO LDV BEAMS
C   FOR GAMMA = 1.03 DEGREES USE CARD 1
C   CARD 1 REAL*8 GSC(2,2)/.017969D0, 0.999838D0, -0.017960D0,0.999838D0
C   FOR GAMMA = .645 DEGREES USE CARD 2
C   CARD 2 REAL*8 GSC(2,2)/ 0.011249D0,0.999367D0,-0.011249D0,0.999367D0
C
C   J-IS THE INDEX FOR THE TWO BEAMS 1-LEFT;2-RIGHT LOOKING TOWARDS THE
C   K-INDEX USED TO CALCULATE VISIBILITY.FOR K 1,BOTH BEAMS ARE IN PHASE
C   SCATTERER;FOR K 2,THE PHASE OF BEAM TWO IS SHIFTED 180 DEGREES.
C
C   IMPLICIT REAL*8(A-H,O-Z)
C   REAL*8 GSC(.2)/.017969D0, 0.999838D0, -0.017960D0,0.999838D0/
C   COMPLEX*16 E1(2),E2(2),E(2),EPER,EHOZ
C   COMMON/INPUT/AL,WAVE,K,OUT
C   COMMON/PAIR/RAD, FN
C   COMMON/DIAG/PHIM
C   COMMON/CONF/ X1,X2,V1,Y2,XX
C   DIMENSION X(2),W(2),ARG(2)
C   DIMENSION CSH(2,2),PSI(2),PHI(2)
C
C   LOGICAL ONCE/.FALSE./
C   LOGICAL OUT
C   DELT1=0.0D0
C   IF (ONCE) GO TO 110
C   ONCE=.TRUE.
C
C
C   P1 = 4.0D0 * DATAN( 1.0D0)
C   DEG = 180.0 / PI
C   GAM=DARSIN(GSC(1,1))
C   SGAM = GSC(1,1)
C   CGAM = DCOS(GAM)
C   FN=INTERFERENCE FRINGE IN MICRONS
C   FN=((WAVE)/GSC(1,1))/2
110 CONTINUE
C
C   SX1=DSIN(X(1))
C   CX1=DCOS(X(1))
C   SX2=DSIN(X(2))
C   CX2=DCOS(X(2))
C
C   SGN2=1.0D0
C
C   DO 45 J=1,2
C   SGN=(3-2*J)
C   IF( K, EQ, 2 .AND. J, EQ, 2) SGN2=-1.0D0
C   CSH(K,J)=CX1*DCOS(GAM)+SX1*SX2*DSIN(GAM)*SGN
C   CSH(K,J)=CX1* CGAM +SX1*SX2* SGAM * SGN
C   ARG(J)=DARCOS(CSH(K,J))

```

```

      ISN 0036      C      BESEL3      IF(ARG(J) .EQ. 0.0D0) ARG(J) = 0.0001D0
      ISN 0038      C      BESEL3      ANGLE IN RADS BETWEEN OFFSET SCATTERING PLANES AND REF PLANE
      ISN 0039      C      BESEL3      PSI(J)=DARSIN((SCAM*(CX2)/DSIN(ARG(J)))
      ISN 0040      C      BESEL3      AA=AL*DSIN(ARG(J))
      ISN 0041      C      BESEL3      AB=ARG(J)
      ISN 0043      C      BESEL3      IF(.NOT.OUT) PRINT 22,AB
      ISN 0044      C      BESEL3      CALL MIECXU(AB,EPER,EHOZ,DELT)
      ISN 0045      C      BESEL3      IF(.NOT.OUT) PRINT 22,AB,EPER,EHOZ,DELT
      ISN 0046      C      BESEL3      CONVERSION FOR VERTICALLY POLARIZED ILLUMINATION
      ISN 0047      C      BESEL3      PHI(J)=X(2)+(2*J-3)*DATAN(DTAN(PSI(J))*CX1)
      ISN 0048      C      BESEL3      E1(J)=EPER*DSIN(PHI(J))
      ISN 0049      C      BESEL3      E2(J)=EHOZ*DCOS(PHI(J))
      ISN 0050      C      BESEL3      IF (PHIM .LT. APHI) PHIM=APHI
      ISN 0051      C      BESEL3      IF(OUT) GOTO 45
      ISN 0052      C      BESEL3      PRINT 3
      ISN 0053      C      BESEL3      3 FORMAT('0',ARG,SGN,SGN2')
      ISN 0054      C      BESEL3      PRINT 1,ARG(J),SGN,SGN2
      ISN 0055      C      BESEL3      1 FORMAT('0',1P4G14.6)
      ISN 0056      C      BESEL3      45 CONTINUE
      ISN 0057      C      BESEL3      FIELD IN REFERENCE SCATTERING PLANE E2
      ISN 0058      C      BESEL3      E(2) = E2(1)*DCOS(PSI(1)) - E1(1)*DSIN(PSI(1)) +
      ISN 0059      C      BESEL3      1 (E2(2)*DCOS(PSI(2)) + E1(2)*DSIN(PSI(2))) * SGN2
      ISN 0060      C      BESEL3      COMPONENT PERPENDICULAR TO REFERENCE SCATTERING PLANE E1
      ISN 0061      C      BESEL3      E(1)=E2(1)*DSIN(PSI(1))+E1(1)*DCOS(PSI(1))+
      ISN 0062      C      BESEL3      1 (E1(2)*DCOS(PSI(2))-E2(2)*DSIN(PSI(2)))*SGN2
      ISN 0063      C      BESEL3      INTENSITY AT A GIVEN POINT ON THE DETECTOR
      ISN 0064      C      BESEL3      W(K)=E(1)*DCONJG(E(1))+E(2)*DCONJG(E(2))
      ISN 0065      C      BESEL3      IF(DELT1.LT.DELT) DELT1=DELT
      ISN 0066      C      BESEL3      IF (OUT) GOTO 35
      ISN 0067      C      BESEL3      OUT=.TRUE.
      ISN 0068      C      BESEL3      DIA=(AL*WAVE)/PI
      ISN 0069      C      BESEL3      ATIA=X(1)*DEG
      ISN 0070      C      BESEL3      APHI=X(2)*DEG
      ISN 0071      C      BESEL3      PRINT 5
      ISN 0072      C      BESEL3      5 FORMAT('FN',RAD,E(1),E(2),
      ISN 0073      C      BESEL3      1 W(K),K')
      ISN 0074      C      BESEL3      PRINT 7,FN,DIA,E(1),E(2),W(K),K
      ISN 0075      C      BESEL3      7 FORMAT('0',1P7G14.6,15)
      ISN 0076      C      BESEL3      PRINT 9
      ISN 0077      C      BESEL3      9 FORMAT('0',PSI(1),PSI(2),PHI(1),PHI(2))
      ISN 0078      C      BESEL3      1 PHI(2)')
      ISN 0079      C      BESEL3      PRINT 13,PSI(1),PSI(2),PHI(1),PHI(2)

```



\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

SYMBOL	INTERNAL STATEMENT NUMBERS			
SK2	0027	0034		
APII	0049	0049	0068	0079
CGAM	0022	0034		
CSII	0011	0034	0035	
CSOS	0022	0026	0028	
DELT	0043	0044	0061	
DSIN	0025	0027	0038	
DIAN	0046			
EH0Z	0005	0043	0044	
EPER	0005	0043	0044	
ONCE	0012	0012	0015	
PHIM	0008	0049	0049	
SCAM	0021	0034	0038	
SGN2	0029	0032	0055	
WAVE	0006	0023	0066	
ATEIA	0067	0079		
DAIAN	0018	0046		
DELT1	0014	0061	0061	0079
BESEL3	0002			
DARGOS	0035			
DARSIN	0020	0038		
DCONJG	0060	0060		
MIEXCU	0043			

```
*****F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G*****
```

LABEL	DEFINED	REFERENCES
1	0056	0055
3	0054	0053
5	0070	0069
7	0072	0071
9	0074	0073
11	0084	0083
13	0076	0075
17	0081	0079
18	0082	0080
19	0086	0085
20	0088	0087
21	0078	0077
22	0091	0090
35	0092	0093
40	0090	0089
45	0050	0051
110	0024	0015

/ BISEL3 /			SIZE OF PROGRAM 001242			HEXADECIMAL BYTES		
NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	TYPE
F	SFA	C*16	000468	J	SFA	I*4	000330	R*8
X	FA	R*8	000000	AA	S	R*8	000338	R*8
E1	SF	C*16	000488	E2	SF	C*16	000448	R*8
XX	F	R*8	000020	X1	F	R*8	000000	R*8
Y2	F	R*8	000018	ARG	SFA	R*8	000318	R*8
XX2	SFA	R*8	0000360	DIG	SFA	R*8	000368	R*8
				K	FA	C	000010	R*8
				AB	SFA	R*8	000340	R*8
				FN	SF	C	000008	R*8
				X2	F	R*8	000008	R*8
				BJ1	F	R*8	000350	R*8
				DIA	SF	R*8	000370	R*8
				AL	F	C	000000	R*8
				PI	SF	C	000348	R*8
				V1	F	R*8	000010	R*8
				CX1	SFA	R*8	000358	R*8
				GAM	SFA	R*8	000378	R*8

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NAME	VAR.	NAME	REL.	ADDR.	VAR.	NAME	REL.	ADDR.	VAR.	NAME	REL.	ADDR.
GSC	FA	R*8		0000408	OUT S	C		0000014	PHI	SFA		0000428
RAD		R*8		NR	SCN	SI		000380	SI			000388
API1	SF	R*8		000398	CCAM	SF		0003A0	SFA			000388
DELT	SFA	R*8		0003A8	DSIN	FA	XF	000000	DIAN	FA	XF	000408
EP1R	SFA	R*8		0003C8	ONCL	S		000334	PHIM	SI	C	000000
SCN2	SF	R*8		0003B8	WAVE	F	C	000008	AL11A	SF		000000
DELT1	SF	R*8		0003C8	COMPY#			000000	BESEL3			0003C0
DARSIN	F	XF		000000	IBCOM#			000000	MIECKU	SF	XF	000300
												000000

\*\*\*\*\* COMMON INFORMATION \*\*\*\*\*

NAME OF COMMON BLOCK	* INPUT*	SIZE OF BLOCK	000018	HEXADECIMAL BYTES	
VAR. NAME	REL. ADDR.	VAR. NAME	REL. ADDR.	VAR. NAME	REL. ADDR.
AL	R*8	000000		000008	000010

NAME OF COMMON BLOCK	* PARM*	SIZE OF BLOCK	000010	HEXADECIMAL BYTES	
VAR. NAME	REL. ADDR.	VAR. NAME	REL. ADDR.	VAR. NAME	REL. ADDR.
RAD	R*8	000000	NR	000008	

NAME OF COMMON BLOCK	* DIAG*	SIZE OF BLOCK	000008	HEXADECIMAL BYTES	
VAR. NAME	REL. ADDR.	VAR. NAME	REL. ADDR.	VAR. NAME	REL. ADDR.
PHIM	R*8	000000			

NAME OF COMMON BLOCK	* COM7*	SIZE OF BLOCK	000028	HEXADECIMAL BYTES	
VAR. NAME	REL. ADDR.	VAR. NAME	REL. ADDR.	VAR. NAME	REL. ADDR.
XT	R*8	000000			
XX	R*8	000020			

SOURCE STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR
110	24	000670	35	92	0011F6

COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	0005C8	200001	33	000750
100004	33	00075E	100007	38	000824
100008	42	0008F0	100011	46	000950
100012	50	000ACE	100015	58	000B4A
200002	60	000EC2	100018	65	000FA6
200003	87	001180			

FORMAT STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR
3	54	000028	7	72	0000AD
9	74	000088	17	81	000180

DATE 82.354/10.15.07  
20 88 0001CC

FORTAN H EXTENDED

OS/360

BESEL3

\*LEVEL 2.3.0 (JUNE 78)

18 82 00018C  
22 91 0001E8

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE {LINECOUNT(60) SIZE(MAX) AUTOBBI (NONE)}

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODCK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 92, PROGRAM SIZE = 14674, SUBPROGRAM NAME = BESEL3

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

\*STATISTICS\* NO DIAGNOSTICS THIS STEP

84K BYTES OF CORE NOT USED





\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

INTERNAL STATEMENT NUMBERS

DIMAG 0015 0017  
DREAL 0014 0016  
VIBRA 0002  
INDICE 0003 0006 0007

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

LABEL DEFINED REFERENCES

32 0020 0008  
33 0021 0018

SIZE OF PROGRAM 0005EA HEXADECIMAL BYTES

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
B	F	C	000000	I	SFA	I*4	000014	J	F	I*4	0000F8	M	SFA	I*4	0000EC
AB	F	XF	000000	A1	S	R*8	0000F8	AB	SF	C*16	000128	DB	F	XF	000000
MA	SF	C*16	000138	AA2	S	R*8	000100	AA2	S	R*8	000108	EPS	S	R*8	000110
ETA	F	XF	000000	AA2	S	R*8	000118	BETA	FA	C	000000	DETA	F	XF	000000
ELC	SFA	XR	000000	IMAG	SFA	XR	000000	AIRIN	F	C	000000	ALPHA	F	C	000000
VIBRA			0000F0	COMPY#	XI	C*16	000000	GDDVD#	XF	C*16	000000	INDICE	F	C	000008

\*\*\*\*\*COMMON INFORMATION\*\*\*\*\*

NAME OF COMMON BLOCK \* COM1\* SIZE OF BLOCK 001FH8 HEXADECIMAL BYTES

VAR.	NAME	TYPE	REL.	ADDR.	VAR.	NAME	TYPE	REL.	ADDR.	VAR.	NAME	TYPE	REL.	ADDR.
B		R*8		000000										

NAME OF COMMON BLOCK \* COM3\* SIZE OF BLOCK 000010 HEXADECIMAL BYTES

VAR.	NAME	TYPE	REL.	ADDR.	VAR.	NAME	TYPE	REL.	ADDR.	VAR.	NAME	TYPE	REL.	ADDR.
BETA		C*16		000000										

NAME OF COMMON BLOCK \* COM4\* SIZE OF BLOCK 000018 HEXADECIMAL BYTES

VAR.	NAME	TYPE	REL.	ADDR.	VAR.	NAME	TYPE	REL.	ADDR.	VAR.	NAME	TYPE	REL.	ADDR.
AIRIN		R*8		000000	INDICE		C*16		000008					

NAME OF COMMON BLOCK \* COM5\* SIZE OF BLOCK 000008 HEXADECIMAL BYTES

VAR.	NAME	TYPE	REL.	ADDR.	VAR.	NAME	TYPE	REL.	ADDR.	VAR.	NAME	TYPE	REL.	ADDR.
ALPHA		R*8		000000	NR									

SOURCE STATEMENT LABELS

LABEL ISN ADDR  
32 20 000562  
33 21 000578

\*LEVEL 2.3.0 (JUNE 78) VIBRA OS/360 FORTRAN H EXTENDED DATE 82.291/17.21.16 PAGE 3

COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	000110	100002	9	000230	200001	13	0004BA
200003	19	000546	200004	19	000554	200002	19	000538

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODICK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 21, PROGRAM SIZE = 1514, SUBPROGRAM NAME = VIBRA

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED



\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

SYMBOL INTERNAL STATEMENT NUMBERS  
ALPHAC 0005 0009 0023  
BESSEL 0002

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

LABEL DEFINED REFERENCES  
1 0018 0015  
2 0028 0022  
12 0015 0012  
13 0029 0019 0026

/ BESSEL / SIZE OF PROGRAM 00041C HEXADECIMAL BYTES

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
B SF	XR	R*8	000000	I SF	1*4	000018	0000EC	X SF			0000F0
I SF	FA	R*8	000014	NN SF	1*4	000018	000118	NN SF			0000FC
RAP F	XF	C*16	000000	DCOS F	XF	000000	000128	DSIN F	XF		000000
ALPHA FA	C	R*8	000000	DLN02 SF	R*8	000108	000000	ALPHAC SFA			000138
BESSEL		R*4	000100								

\*\*\*\*\* COMMON INFORMATION \*\*\*\*\*

NAME OF COMMON BLOCK \* COM5\* SIZE OF BLOCK 000008 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
ALPHA	R*8	000000						

SOURCE STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
12	15	0002AA	1	18	000328	13	29	0003F0

COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	0001BC	100002	14	0002A2	100004	19	00033E
100005	21	00034C	100006	23	00035C			

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 29, PROGRAM SIZE = 1100, SUBPROGRAM NAME = BESSEL

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSIMI

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTOUBL(NONE)  
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSIMI XREF NOALC NOANSF TERM IBM FLAG(1)

```

C
C
C      SECOND ORDER RICCATTI-BESSSEL FUNCTION CALC.
C
      SUBROUTINE NEUMAN(I,NE,I)
      COMMON/COM5/ALPHA
      REAL*8 NE(1001),ALPHA
      NE(1)=DCOS(ALPHA)
      NE(2)=(DCOS(ALPHA)/ALPHA)+DSIN(ALPHA)
      IF((1-2).LE.0.0) GO TO 52
      DO 53 I=3,L,I
      X=DBLE(FLOAT(I))
      NE(I)=(2.0D+00*(X-1.5D+00)/ALPHA)*NE(I-1)-NE(I-2)
      IF(NE(I).GT.1.0D+30) GO TO 52
      CONTINUE
      RETURN
      END
      53
      52
      ISN 0002
      ISN 0003
      ISN 0004
      ISN 0005
      ISN 0006
      ISN 0007
      ISN 0008
      ISN 0009
      ISN 0010
      ISN 0011
      ISN 0012
      ISN 0014
      ISN 0015
      ISN 0016
      C 10
      C 20
      C 30
      C 40
      C 50
      C 60
      C 70
      C 80
      C 90
      C 100
      C 110
      C 120
      C 130
      C 140
      C 150
      C 160

```

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

```

SYMBOL  INTERNAL STATEMENT NUMBERS
I       0002 0009 0010 0011 0011 0012
L       0002 0007 0009
X       0010 0011
NE      0002 0004 0005 0006 0011 0011 0012
DBLE    0010
DCOS    0005 0006
DSIN    0006
ALPHA   0003 0004 0005 0006 0006 0011
FLOAT   0010
NEUMAN  0002

```

\*\*\*\*\*FORTRAN CROSS REFERENCE LISTING\*\*\*\*\*

```

LABEL  DEFINED  REFERENCES
52     0015     0007 0012
53     0014     0009

```

/ NEUMAN / SIZE OF PROGRAM 00029A HEXADECIMAL BYTES

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
I SFA	F	R*8	000080	L	F	I*4	0000B4
DCOS	F	R*8	000000	DSIN	F	R*8	000000
				ALPHA	FA	C	R*8
				NE	SF	XR	0000B8
				NEUMAN			000000
							0000BC

\*\*\*\*\*COMMON INFORMATION\*\*\*\*\*

NAME OF COMMON BLOCK \* COM5\* SIZE OF BLOCK 000008 HEXADECIMAL BYTES

VAR. NAME TYPE REL. ADDR. VAR. NAME TYPE REL. ADDR. VAR. NAME TYPE REL. ADDR.  
ALPHA R\*8 000000

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSINT

```

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE L INLCOUNT(60) SIZE(MAX) AUTODDL(NONE)
SOURCE EBCDIC NOLIST NODICK OBJECT MAP NOFORMAT GOSIMT XREF NOALC NOANSF TERM IBM FLAG(1)

```

```

C      C      C      C      C      C      C      C      C      C      C
1SN 0002    DOUBLE PRECISION FUNCTION DB(M)
1SN 0003    COMMON/COM1/B(1001)/COM5/ALPHA
1SN 0004    DOUBLE PRECISION B, ALPHA
1SN 0005    X=DBLE(FLOAT(M))
1SN 0006    DB=B*(M-1)-((X-1.0D0)/ALPHA)*B(M)
1SN 0007    RETURN
1SN 0008    END

```

\*\*\*\*\* CROSS REFERENCE LISTING \*\*\*\*\*

SYMBOL	INTERNAL STATEMENT NUMBERS
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14
15	15
16	16
17	17
18	18
19	19
20	20
21	21
22	22
23	23
24	24
25	25
26	26
27	27
28	28
29	29
30	30
31	31
32	32
33	33
34	34
35	35
36	36
37	37
38	38
39	39
40	40
41	41
42	42
43	43
44	44
45	45
46	46
47	47
48	48
49	49
50	50
51	51
52	52
53	53
54	54
55	55
56	56
57	57
58	58
59	59
60	60
61	61
62	62
63	63
64	64
65	65
66	66
67	67
68	68
69	69
70	70
71	71
72	72
73	73
74	74
75	75
76	76
77	77
78	78
79	79
80	80
81	81
82	82
83	83
84	84
85	85
86	86
87	87
88	88
89	89
90	90
91	91
92	92
93	93
94	94
95	95
96	96
97	97
98	98
99	99
100	100

B	0003	0004	0006	0006
M	0002	0005	0006	0006
X	0005	0006		
DB	0002	0006		
DB1 F	0005			
AL PIA	0003	0004	0006	
FLOAT	0005			

NAME		TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
B	F	C	R*8	000000	M	FA	I*4	000094	X	SF	R*4	000098
ALPHA	F	C	R*8	000000								

NAME OF COMMON BLOCK	* COM1*	SIZE OF BLOCK	001148	HEXADECIMAL BYTES
COMMON BLOCK 1	1	100	000000	000000
COMMON BLOCK 2	2	200	000000	000000
COMMON BLOCK 3	3	300	000000	000000
COMMON BLOCK 4	4	400	000000	000000
COMMON BLOCK 5	5	500	000000	000000
COMMON BLOCK 6	6	600	000000	000000
COMMON BLOCK 7	7	700	000000	000000
COMMON BLOCK 8	8	800	000000	000000
COMMON BLOCK 9	9	900	000000	000000
COMMON BLOCK 10	10	1000	000000	000000
COMMON BLOCK 11	11	1100	000000	000000
COMMON BLOCK 12	12	1200	000000	000000
COMMON BLOCK 13	13	1300	000000	000000
COMMON BLOCK 14	14	1400	000000	000000
COMMON BLOCK 15	15	1500	000000	000000
COMMON BLOCK 16	16	1600	000000	000000
COMMON BLOCK 17	17	1700	000000	000000
COMMON BLOCK 18	18	1800	000000	000000
COMMON BLOCK 19	19	1900	000000	000000
COMMON BLOCK 20	20	2000	000000	000000
COMMON BLOCK 21	21	2100	000000	000000
COMMON BLOCK 22	22	2200	000000	000000
COMMON BLOCK 23	23	2300	000000	000000
COMMON BLOCK 24	24	2400	000000	000000
COMMON BLOCK 25	25	2500	000000	000000
COMMON BLOCK 26	26	2600	000000	000000
COMMON BLOCK 27	27	2700	000000	000000
COMMON BLOCK 28	28	2800	000000	000000
COMMON BLOCK 29	29	2900	000000	000000
COMMON BLOCK 30	30	3000	000000	000000
COMMON BLOCK 31	31	3100	000000	000000
COMMON BLOCK 32	32	3200	000000	000000
COMMON BLOCK 33	33	3300	000000	000000
COMMON BLOCK 34	34	3400	000000	000000
COMMON BLOCK 35	35	3500	000000	000000
COMMON BLOCK 36	36	3600	000000	000000
COMMON BLOCK 37	37	3700	000000	000000
COMMON BLOCK 38	38	3800	000000	000000
COMMON BLOCK 39	39	3900	000000	000000
COMMON BLOCK 40	40	4000	000000	000000
COMMON BLOCK 41	41	4100	000000	000000
COMMON BLOCK 42	42	4200	000000	000000
COMMON BLOCK 43	43	4300	000000	000000
COMMON BLOCK 44	44	4400	000000	000000
COMMON BLOCK 45	45	4500	000000	000000
COMMON BLOCK 46	46	4600	000000	000000
COMMON BLOCK 47	47	4700	000000	000000
COMMON BLOCK 48	48	4800	000000	000000
COMMON BLOCK 49	49	4900	000000	000000
COMMON BLOCK 50	50	5000	000000	000000
COMMON BLOCK 51	51	5100	000000	000000
COMMON BLOCK 52	52	5200	000000	000000
COMMON BLOCK 53	53	5300	000000	000000
COMMON BLOCK 54	54	5400	000000	000000
COMMON BLOCK 55	55	5500	000000	000000
COMMON BLOCK 56	56	5600	000000	000000
COMMON BLOCK 57	57	5700	000000	000000
COMMON BLOCK 58	58	5800	000000	000000
COMMON BLOCK 59	59	5900	000000	000000
COMMON BLOCK 60	60	6000	000000	000000
COMMON BLOCK 61	61	6100	000000	000000
COMMON BLOCK 62	62	6200	000000	000000
COMMON BLOCK 63	63	6300	000000	000000
COMMON BLOCK 64	64	6400	000000	000000
COMMON BLOCK 65	65	6500	000000	000000
COMMON BLOCK 66	66	6600	000000	000000
COMMON BLOCK 67	67	6700	000000	000000
COMMON BLOCK 68	68	6800</		

[illegible][illegible][illegible]

## COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
1000001	2	0001008						

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL.(NONE)

\*OPTIONS IN EFFECT\*SOURCE IBCDIC NOLIST NODECK OBJECT MAP NOFORMAT QOSIMI XREF NOALC NOANSF TERM IBM FLAG(1)

\*LEVEL 2.3.0 (JUNE 78)

OS/360 FORTRAN H EXTENDED

DATE 82.291/17.21.17

PAGE 2

SOURCE STATEMENT LABELS

LABEL ISN ADDR  
53 14 000228

LABEL ISN ADDR  
52 15 00023E

LABEL ISN ADDR  
LABEL ISN ADDR

COMPILER GENERATED LABELS

LABEL ISN ADDR  
100001 2 000108

LABEL ISN ADDR  
100002 9 00018A

LABEL ISN ADDR  
100003 10 000192

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE (LINECOUNT(60) SIZE(MAX) AUTODBL(NONE))

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODICK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 15, PROGRAM SIZE = 666, SUBPROGRAM NAME = NEUMAN

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED



```

OPTIONS IN EFFECT:  NAME(MAIN) NOOPTIMIZE LINECOUNT(GO) SIZE{MAX} AUTODBL(NONE)
                     SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSINT XREF
                     NOALC NOANSF TERM IBM FLAG(1)

```

**GILBERT**

\*\*\*\*\*  
COMMON INFORMATION  
\*\*\*\*\*

NAME OF COMMON BLOCK		*	COM5*	SIZE OF BLOCK	000008	HEXADECIMAL BYTES		
VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
ALPHA	R#8	000000						

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
1000001	2	00000D8						

```
*OPTIONS IN {EFFECT*NAME(MAIN) NOOPTIMIZE LINESCOUNT(60) SIZE(MAX) AUTODBL(NONE)}
```

*LEVEL 2.3.0 (JUNE 78)	OS/360 FORTRAN II EXTENDED	DATE 82.291/17.21.20	PAGE 2
*STATISTICS* SOURCE STATEMENTS =	1. PROGRAM SIZE =	392, SUBPROGRAM NAME = DB	
*STATISTICS* NO DIAGNOSTICS GENERATED			
***** END OF COMPILATION *****			
		108K BYTES OF CORE NOT USED	

```

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
SOURCE EBCDIC NOLIST NODECK OBJECT MAP RORFORMAT GOSIMIT XREF NOALC NOANSF TERM IBM FLAG(1)

```

[illegible]

\*\*\*\*\*F O R T R A N   C R O S S   R E F E R E N C E   L I S T I N G \*\*\*\*\*

SYMBOL	INTERNAL STATEMENT	NUMBERS
$\alpha$	the set of all $\alpha$	1
$\beta$	the set of all $\beta$	2
$\gamma$	the set of all $\gamma$	3
$\delta$	the set of all $\delta$	4
$\epsilon$	the set of all $\epsilon$	5
$\zeta$	the set of all $\zeta$	6
$\eta$	the set of all $\eta$	7
$\theta$	the set of all $\theta$	8
$\iota$	the set of all $\iota$	9
$\kappa$	the set of all $\kappa$	10
$\lambda$	the set of all $\lambda$	11
$\mu$	the set of all $\mu$	12
$\nu$	the set of all $\nu$	13
$\xi$	the set of all $\xi$	14
$\omicron$	the set of all $\omicron$	15
$\pi$	the set of all $\pi$	16
$\rho$	the set of all $\rho$	17
$\sigma$	the set of all $\sigma$	18
$\tau$	the set of all $\tau$	19
$\upsilon$	the set of all $\upsilon$	20
$\phi$	the set of all $\phi$	21
$\chi$	the set of all $\chi$	22
$\psi$	the set of all $\psi$	23
$\omega$	the set of all $\omega$	24
$\Omega$	the set of all $\Omega$	25
$\Theta$	the set of all $\Theta$	26
$\Lambda$	the set of all $\Lambda$	27
$\Sigma$	the set of all $\Sigma$	28
$\Pi$	the set of all $\Pi$	29
$\Phi$	the set of all $\Phi$	30
$\Psi$	the set of all $\Psi$	31
$\Xi$	the set of all $\Xi$	32
$\Upsilon$	the set of all $\Upsilon$	33
$\Gamma$	the set of all $\Gamma$	34
$\Delta$	the set of all $\Delta$	35
$\Lambda$	the set of all $\Lambda$	36
$\Sigma$	the set of all $\Sigma$	37
$\Pi$	the set of all $\Pi$	38
$\Phi$	the set of all $\Phi$	39
$\Psi$	the set of all $\Psi$	40
$\Xi$	the set of all $\Xi$	41
$\Upsilon$	the set of all $\Upsilon$	42
$\Gamma$	the set of all $\Gamma$	43
$\Delta$	the set of all $\Delta$	44
$\Lambda$	the set of all $\Lambda$	45
$\Sigma$	the set of all $\Sigma$	46
$\Pi$	the set of all $\Pi$	47
$\Phi$	the set of all $\Phi$	48
$\Psi$	the set of all $\Psi$	49
$\Xi$	the set of all $\Xi$	50
$\Upsilon$	the set of all $\Upsilon$	51
$\Gamma$	the set of all $\Gamma$	52
$\Delta$	the set of all $\Delta$	53
$\Lambda$	the set of all $\Lambda$	54
$\Sigma$	the set of all $\Sigma$	55
$\Pi$	the set of all $\Pi$	56
$\Phi$	the set of all $\Phi$	57
$\Psi$	the set of all $\Psi$	58
$\Xi$	the set of all $\Xi$	59
$\Upsilon$	the set of all $\Upsilon$	60
$\Gamma$	the set of all $\Gamma$	61
$\Delta$	the set of all $\Delta$	62
$\Lambda$	the set of all $\Lambda$	63
$\Sigma$	the set of all $\Sigma$	64
$\Pi$	the set of all $\Pi$	65
$\Phi$	the set of all $\Phi$	66
$\Psi$	the set of all $\Psi$	67
$\Xi$	the set of all $\Xi$	68
$\Upsilon$	the set of all $\Upsilon$	69
$\Gamma$	the set of all $\Gamma$	70
$\Delta$	the set of all $\Delta$	71
$\Lambda$	the set of all $\Lambda$	72
$\Sigma$	the set of all $\Sigma$	73
$\Pi$	the set of all $\Pi$	74
$\Phi$	the set of all $\Phi$	75
$\Psi$	the set of all $\Psi$	76
$\Xi$	the set of all $\Xi$	77
$\Upsilon$	the set of all $\Upsilon$	78
$\Gamma$	the set of all $\Gamma$	79
$\Delta$	the set of all $\Delta$	80
$\Lambda$	the set of all $\Lambda$	81
$\Sigma$	the set of all $\Sigma$	82
$\Pi$	the set of all $\Pi$	83
$\Phi$	the set of all $\Phi$	84
$\Psi$	the set of all $\Psi$	85
$\Xi$	the set of all $\Xi$	86
$\Upsilon$	the set of all $\Upsilon$	87
$\Gamma$	the set of all $\Gamma$	88
$\Delta$	the set of all $\Delta$	89
$\Lambda$	the set of all $\Lambda$	90
$\Sigma$	the set of all $\Sigma$	91
$\Pi$	the set of all $\Pi$	92
$\Phi$	the set of all $\Phi$	93
$\Psi$	the set of all $\Psi$	94
$\Xi$	the set of all $\Xi$	95
$\Upsilon$	the set of all $\Upsilon$	96

0002 0004 0005

AB 0002 0005

0004 0005

RAP 0003 0005

BETA 0002 0003 0005

3780	4000
------	------

/		AB /		SIZE OF PROGRAM 0001E4 HEXADECIMAL BYTES									
NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.		
M	FA	I*4	00009C	AB	S	C*16	0000A8						
BEIA	FA	C*16	000098	CDDVD#	XF	C*16	000000	RAP	F	C*16	000000		

## COMPILER GENERATED LABELS

LABEL	ISN	ADDR
100001	2	0000FC

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINFCOUNT(60) SIZE(MAX) AUTODBL(NONE)

```
*OPTIONS IN EFFECT*SOURCE FBCDIC NOLIST NODECK OBJECT MAP NOFORMAT COSIMT XREF NOALC NOANSF TERM IBM FLAG(1)
```

```
*STATISTICS*
SOURCE STATEMENTS = 6, PROGRAM SIZE = 484, SUBPROGRAM NAME = AB
```

\*STATISTICS# NO DIAGNOSTICS GENERATED

\*\*\*\*\*  
END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED

\*LEVEL 2.3.0 (JUNE 78)

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DATE 82.291/17.21.20

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\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODICK OBJECT MAP NOFORMAT COSINT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS =

7, PROGRAM SIZE

392, SUBPROGRAM NAME = DN

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED

\*LEVEL 2.3.0 (JUNE 78)

REQUISITED OPTIONS: XREF, MAP, OPT=0, GOSINT

```

OPTIONS IN EFFECT: NAME(MA) NOOPTIMIZE L INECOUNT(60) SIZE(MAX) AUTODBL(NONE)
SOURCE          PIC NO1ST NODECK OBJECT MAP NOFORMAT GOSIM1 XREF NOALC NOANSF TERM IBM FLAG(1)

```

C	10		
C	20		
1SN 0002	30	COMPLEX FUNCTION RAP*16(1,Z')	C
1SN 0003	40	COMPLEX*16 Z',AR(5000),BR(5000),S,V	C
	50		C
1SN 0004	60	CALL FRAC(1,Z,AR,BR,K)	C
	70		C
	80		C
1SN 0005	90	S=AR(1)	C
1SN 0006	100	V=(1.0D0,0.0D0)	C
1SN 0007	110	I=K-1	C
1SN 0008	120	DO 2 J=1,I	C
1SN 0009	130	S=S*AR(J+1)	C
1SN 0010	140	V=V*BR(J)	C
1SN 0011	150	IF(J.GQ.4999) GO TO 5	C
1SN 0012	160	CONTINUE	C
1SN 0013	170	RAP S/V	C
1SN 0014	180	RETURN	C
1SN 0015		END	C
1SN 0016			

```

*LEVEL 2.3.0 (JUNE 78)
2 13 027318 5 14 02732E
OS/360 FORTRAN II EXTENDED DATE 82.291/17.21.21

COMPILER GENERATED LABELS
  LABEL ISN ADDR LABEL ISN ADDR LABEL ISN ADDR
100001 2 027248 100002 9 02728A

*OPTIONS IN EFFECT*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
*OPTIONS IN EFFECT*SOURCE EBCDIC NOLIST NODICK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)
*STATISTICS* SOURCE STATEMENTS = 15, PROGRAM SIZE = 160690, SUBPROGRAM NAME = RAP
*STATISTICS* NO DIAGNOSTICS GENERATED
***** END OF COMPILATION *****
108K BYTES OF CORE NOT USED

```



SOURCE STATEMENT LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
1	17	013D44	2	18	013D5A			

COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	013A20	100002	10	013B0C	200001	16	013D36

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 18, PROGRAM SIZE = 81396, SUBPROGRAM NAME = FRAC

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED



```

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM (BM FLAG(1)

```

[illegible]

\*\*\*\*\*FORTAN CROSS REFERENCE LISTING\*\*\*\*\*

SYMBOL	INTERNAL STATEMENT NUMBERS
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14
15	15
16	16
17	17
18	18
19	19
20	20
21	21
22	22
23	23
24	24
25	25
26	26
27	27
28	28
29	29
30	30
31	31
32	32
33	33
34	34
35	35
36	36
37	37
38	38
39	39
40	40
41	41
42	42
43	43
44	44
45	45
46	46
47	47
48	48
49	49
50	50
51	51
52	52
53	53
54	54
55	55
56	56
57	57
58	58
59	59
60	60
61	61
62	62
63	63
64	64
65	65
66	66
67	67
68	68
69	69
70	70
71	71
72	72
73	73
74	74
75	75
76	76
77	77
78	78
79	79
80	80
81	81
82	82
83	83
84	84
85	85
86	86
87	87
88	88
89	89
90	90
91	91
92	92
93	93
94	94
95	95
96	96
97	97
98	98
99	99
100	100

SYMBOL	INTERPOLATED
I	0002 0005
M	0002 0006
W	0004 0007
Z	0002 0003
MM	0006 0008
WW	0004 0005
AAA	0002 0008
DBL	0005 0006
FL0AT	0005 0006

[illegible]

## COMPILER GENERATED LABELS

LABEL	ISN	ADDR
100001	2	00013C

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

```
*STATISTICS*
SOURCE STATEMENTS = 9, PROGRAM SIZE = 662, SUBPROGRAM NAME = AAA
```

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\*  
END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED

\*LEVEL 2.3.0 (JUNE 78)

REQUESTED OPTIONS: XREF,MAP,OPT=0,GOSIMI

```

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINKCOUNT(60) SIZE(MAX) AUTOUBL(NONE)
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

```

10	C	
20	C	
30	C	
40	C	
50	C	
60	C	
70	C	
80	C	
90	C	
100	C	
110	C	
120	C	
130	C	

```

      HANKEL FUNCTION AND DERIVATIVE CALCULATION

      COMPLEX FUNCTION ETA*16(J)
      COMMON/COM1/B(1001)/COM2/NE(1001)
      COMPLEX*16 Z
      DOUBLE PRECISION B,NE
      Z=(0.0D0,1.0D0)
      ETA=B(J)+Z*NE(J)
      RETURN
      END
  
```

10	C	
20	C	
30	C	
40	C	
50	C	
60	C	
70	C	
80	C	
90	C	
100	C	
110	C	
120	C	
130	C	

\*\*\*\*\* CROSS REFERENCE LISTING \*\*\*\*\*

SYMBOL	INTERNAL STATEMENT	NUMBERS
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	8	8
9	9	9
10	10	10
11	11	11
12	12	12
13	13	13
14	14	14
15	15	15
16	16	16
17	17	17
18	18	18
19	19	19
20	20	20
21	21	21
22	22	22
23	23	23
24	24	24
25	25	25
26	26	26
27	27	27
28	28	28
29	29	29
30	30	30
31	31	31
32	32	32
33	33	33
34	34	34
35	35	35
36	36	36
37	37	37
38	38	38
39	39	39
40	40	40
41	41	41
42	42	42
43	43	43
44	44	44
45	45	45
46	46	46
47	47	47
48	48	48
49	49	49
50	50	50
51	51	51
52	52	52
53	53	53
54	54	54
55	55	55
56	56	56
57	57	57
58	58	58
59	59	59
60	60	60
61	61	61
62	62	62
63	63	63
64	64	64
65	65	65
66	66	66
67	67	67
68	68	68
69	69	69
70	70	70
71	71	71
72	72	72
73	73	73
74	74	74
75	75	75
76	76	76
77	77	77
78	78	78
79	79	79
80	80	80
81	81	81
82	82	82
83	83	83
84	84	84
85	85	85
86	86	86
87	87	87
88	88	88
89	89	89
90	90	90
91	91	91
92	92	92
93	93	93
94	94	94
95	95	95
96	96	96
97	97	97
98	98	98
99	99	99
100	100	100

B	0003	0005	0007
J	0002	0007	0007
Z	0004	0006	0007
NE	0003	0005	0007
TA	0002	0007	

88

NAME		TAG		TYPE		ADD.		NAME		TAG		TYPE		ADD.	
B F C		F C		R*8		C*16		Z SF		C*16		R*8		C*16	
ETA S		C		C		000000		000000		C		C		000000	
COMPY#		XF		C*16		000000		000000		C		C		000000	
J		F		I*4		000090		000090		C		C		000000	

\*\*\*\*\*  
COMMON INFORMATION

NAME OF COMMON BLOCK	* COM1*	SIZE OF BLOCK	001F48 HEXADECIMAL BYTES
COMMON BLOCK 1	1	100	000000
COMMON BLOCK 2	2	200	000000
COMMON BLOCK 3	3	300	000000
COMMON BLOCK 4	4	400	000000
COMMON BLOCK 5	5	500	000000
COMMON BLOCK 6	6	600	000000
COMMON BLOCK 7	7	700	000000
COMMON BLOCK 8	8	800	000000
COMMON BLOCK 9	9	900	000000
COMMON BLOCK 10	10	1000	000000
COMMON BLOCK 11	11	1100	000000
COMMON BLOCK 12	12	1200	000000
COMMON BLOCK 13	13	1300	000000
COMMON BLOCK 14	14	1400	000000
COMMON BLOCK 15	15	1500	000000
COMMON BLOCK 16	16	1600	000000
COMMON BLOCK 17	17	1700	000000
COMMON BLOCK 18	18	1800	000000
COMMON BLOCK 19	19	1900	000000
COMMON BLOCK 20	20	2000	000000
COMMON BLOCK 21	21	2100	000000
COMMON BLOCK 22	22	2200	000000
COMMON BLOCK 23	23	2300	000000
COMMON BLOCK 24	24	2400	000000
COMMON BLOCK 25	25	2500	000000
COMMON BLOCK 26	26	2600	000000
COMMON BLOCK 27	27	2700	000000
COMMON BLOCK 28	28	2800	000000
COMMON BLOCK 29	29	2900	000000
COMMON BLOCK 30	30	3000	000000
COMMON BLOCK 31	31	3100	000000
COMMON BLOCK 32	32	3200	000000
COMMON BLOCK 33	33	3300	000000
COMMON BLOCK 34	34	3400	000000
COMMON BLOCK 35	35	3500	000000
COMMON BLOCK 36	36	3600	000000
COMMON BLOCK 37	37	3700	000000
COMMON BLOCK 38	38	3800	000000
COMMON BLOCK 39	39	3900	000000
COMMON BLOCK 40	40	4000	000000
COMMON BLOCK 41	41	4100	000000
COMMON BLOCK 42	42	4200	000000
COMMON BLOCK 43	43	4300	000000
COMMON BLOCK 44	44	4400	000000
COMMON BLOCK 45	45	4500	000000
COMMON BLOCK 46	46	4600	000000
COMMON BLOCK 47	47	4700	000000
COMMON BLOCK 48	48	4800	000000
COMMON BLOCK 49	49	4900	000000
COMMON BLOCK 50	50	5000	000000
COMMON BLOCK 51	51	5100	000000
COMMON BLOCK 52	52	5200	000000
COMMON BLOCK 53	53	5300	000000
COMMON BLOCK 54	54	5400	000000
COMMON BLOCK 55	55	5500	000000
COMMON BLOCK 56	56	5600	000000
COMMON BLOCK 57	57	5700	000000
COMMON BLOCK 58	58	5800	000000
COMMON BLOCK 59	59	5900	000000
COMMON BLOCK 60	60	6000	000000
COMMON BLOCK 61	61	6100	000000
COMMON BLOCK 62	62	6200	000000
COMMON BLOCK 63	63	6300	000000
COMMON BLOCK 64	64	6400	000000
COMMON BLOCK 65	65	6500	000000
COMMON BLOCK 66	66	6600	000000
COMMON BLOCK 67	67	6700	000000
COMMON BLOCK 68	68	6800	000000
COMMON BLOCK 69	69	6900	000000
COMMON BLOCK 70	70	7000	000000
COMMON BLOCK 71	71	7100	000000
COMMON BLOCK 72	72	7200	000000
COMMON BLOCK 73	73	7300	000000
COMMON BLOCK 74	74	7400	000000
COMMON BLOCK 75	75	7500	000000
COMMON BLOCK 76	76	7600	000000
COMMON BLOCK 77	77	7700	000000
COMMON BLOCK 78	78	7800	000000
COMMON BLOCK 79	79	7900	000000
COMMON BLOCK 80	80	8000	000000
COMMON BLOCK 81	81	8100	000000
COMMON BLOCK 82	82	8200	000000
COMMON BLOCK 83	83	8300	000000
COMMON BLOCK 84	84	8400	000000
COMMON BLOCK 85	85		

[illegible]

NAME OF COMMON BLOCK	* COM2*	SIZE OF BLOCK	001F48	HEXADECIMAL BYTES
COMMON BLOCK 1	1	100	000000	000000
COMMON BLOCK 2	2	200	000000	000000
COMMON BLOCK 3	3	300	000000	000000
COMMON BLOCK 4	4	400	000000	000000
COMMON BLOCK 5	5	500	000000	000000
COMMON BLOCK 6	6	600	000000	000000
COMMON BLOCK 7	7	700	000000	000000
COMMON BLOCK 8	8	800	000000	000000
COMMON BLOCK 9	9	900	000000	000000
COMMON BLOCK 10	10	1000	000000	000000
COMMON BLOCK 11	11	1100	000000	000000
COMMON BLOCK 12	12	1200	000000	000000
COMMON BLOCK 13	13	1300	000000	000000
COMMON BLOCK 14	14	1400	000000	000000
COMMON BLOCK 15	15	1500	000000	000000
COMMON BLOCK 16	16	1600	000000	000000
COMMON BLOCK 17	17	1700	000000	000000
COMMON BLOCK 18	18	1800	000000	000000
COMMON BLOCK 19	19	1900	000000	000000
COMMON BLOCK 20	20	2000	000000	000000
COMMON BLOCK 21	21	2100	000000	000000
COMMON BLOCK 22	22	2200	000000	000000
COMMON BLOCK 23	23	2300	000000	000000
COMMON BLOCK 24	24	2400	000000	000000
COMMON BLOCK 25	25	2500	000000	000000
COMMON BLOCK 26	26	2600	000000	000000
COMMON BLOCK 27	27	2700	000000	000000
COMMON BLOCK 28	28	2800	000000	000000
COMMON BLOCK 29	29	2900	000000	000000
COMMON BLOCK 30	30	3000	000000	000000
COMMON BLOCK 31	31	3100	000000	000000
COMMON BLOCK 32	32	3200	000000	000000
COMMON BLOCK 33	33	3300	000000	000000
COMMON BLOCK 34	34	3400	000000	000000
COMMON BLOCK 35	35	3500	000000	000000
COMMON BLOCK 36	36	3600	000000	000000
COMMON BLOCK 37	37	3700	000000	000000
COMMON BLOCK 38	38	3800	000000	000000
COMMON BLOCK 39	39	3900	000000	000000
COMMON BLOCK 40	40	4000	000000	000000
COMMON BLOCK 41	41	4100	000000	000000
COMMON BLOCK 42	42	4200	000000	000000
COMMON BLOCK 43	43	4300	000000	000000
COMMON BLOCK 44	44	4400	000000	000000
COMMON BLOCK 45	45	4500	000000	000000
COMMON BLOCK 46	46	4600	000000	000000
COMMON BLOCK 47	47	4700	000000	000000
COMMON BLOCK 48	48	4800	000000	000000
COMMON BLOCK 49	49	4900	000000	000000
COMMON BLOCK 50	50	5000	000000	000000
COMMON BLOCK 51	51	5100	000000	000000
COMMON BLOCK 52	52	5200	000000	000000
COMMON BLOCK 53	53	5300	000000	000000
COMMON BLOCK 54	54	5400	000000	000000
COMMON BLOCK 55	55	5500	000000	000000
COMMON BLOCK 56	56	5600	000000	000000
COMMON BLOCK 57	57	5700	000000	000000
COMMON BLOCK 58	58	5800	000000	000000
COMMON BLOCK 59	59	5900	000000	000000
COMMON BLOCK 60	60	6000	000000	000000
COMMON BLOCK 61	61	6100	000000	000000
COMMON BLOCK 62	62	6200	000000	000000
COMMON BLOCK 63	63	6300	000000	000000
COMMON BLOCK 64	64	6400	000000	000000
COMMON BLOCK 65	65	6500	000000	000000
COMMON BLOCK 66	66	6600	000000	000000
COMMON BLOCK 67	67	6700	000000	000000
COMMON BLOCK 68	68	6800</		

[illegible]

**COMPILER GENERATED LABELS**

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	0000f8						

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

```
#OPTIONS IN EFFECT*SOURCE FBKDC NOLIST NODECK OBJECT MAP NOFORMAT COSTMI XREF NOALC NOANSF TERM IBM FLAG(1)
```

\*LEVEL 2.3.0 (JUNE 78)

REQUESTED OPTIONS: XREF,MAP,OPT=0,COSTMT

OPTIONS IN EFFECT: NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)  
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

```

C
ISN 0002      COMPLEX FUNCTION DETA*16(M)
ISN 0003      COMPLEX*16 Z
ISN 0004      DOUBLE PRECISION DB,DN
ISN 0005      Z=(0.0D0,1.0D0)
ISN 0006      DETA=DB(M)+Z*DN(M)
ISN 0007      RETURN
ISN 0008      END
C          10
C          20
C          30
C          40
C          50
C          60
C          70
C          80
    
```

CROSS REFERENCE LISTING \*\*\*\*\*

INTERNAL STATEMENT NUMBERS

```

SYMBOL  0002 0006 0006
M        0003 0005 0006
Z        0004 0006
DB       0004 0006
DN       0004 0006
DETA     0002 0006
    
```

NAME		TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
M	FA		C*16	000090	Z	SF	XF		DB	F	XF	
DETA	S		C*16	0000A8	CDMPY#				DN	F	XF	

COMPILER GENERATED LABELS

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	0000f8						

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)  
 \*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT COSTMT XREF NOALC NOANSF TERM IBM FLAG(1)  
 \*STATISTICS\* SOURCE STATEMENTS = 7, PROGRAM SIZE = 444, SUBPROGRAM NAME = DETA

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

108K BYTES OF CORE NOT USED

\*LEVEL 2.3.0 (JUNE 78)

\*STATISTICS\* SOURCE STATEMENTS =

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

OS/360 FORTRAN H EXTENDED

8, PROGRAM SIZE =

422, SUBPROGRAM NAME =

ETA

PAGE 2

DATE 82.291/17.21.24

108K BYTES OF CORE NOT USED

\*LEVEL 2.3.0 (JUNE 78)

REQUESTED OPTIONS: XREF,MAP,OPT=0,COSTMT

```

OPTIONS IN EFFECT:  NAME(MAIN) NOOPTIMIZE (LINECOUNT(60) SIZE(MAX) AUTOBL(NONE)
SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSIMI XREF NOALC NOANSF TERM IBM FLAG(1)

```

15N 0002	SUBROUTINE POLY(L,PO,PA,IETA)		
15N 0003	REAL*8 PO(1000),PA(1000),IETA,G		
15N 0004	PO(1)=0.10000D+01		
15N 0005	PO(2)=3.00D*DCOS(IETA)		
15N 0006	PA(1)=DCOS(IETA)		
15N 0007	PA(2)=3.00D*DCOS(2.0D0*IETA)		
15N 0008	DO 2 I=3,1,1		
15N 0009	G=DCOS(IETA)*PO(I-1)		
15N 0010	PO(1)=G+G-PO(I-2)+(G-PO(I-2))/DBLE(FLOAT(I-1))		
15N 0011	PA(1)=DBLE(FLOAT(I))*PO(1)*DCOS(IETA)-DBLE(FLOAT(I+1))*PO(I-1)		
15N 0012	CONTINUE		
15N 0013	RETURN		
15N 0014	END		

*****F O R T R A N	C R O S S	R E F E R E N C E	L I S T I N G *****
--------------------	-----------	-------------------	---------------------

SYMBOL	INTERNAL STATEMENT NUMBERS	STATEMENT	ADDRESS	OPERATION	OPERANDS	RELATION	FLAG	REMARKS
C I L	0003	0009	0010	0010				
	0008	0009	0010	0010				
	0002	0008						
	0002	0003	0006	0007	0011			
P A	0002	0003	0004	0005	0009	0010	0010	0011
P O	0002	0010	0011	0011				
D B L E	0010	0011	0011					
O C C O S	0005	0006	0007	0009	0011			
P O L Y	0002							
T E T A	0002	0003	0005	0006	0007	0009	0011	
F L O A T	0010	0011	0011					

\*\*\*\*\*CROSS REFERENCE LISTING\*\*\*\*\*

LABEL	DEFINED	REFERENCES
2	0012	0008

POLY / SIZE OF PROGRAM 00038A HEXADECIMAL BYTES

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
G SF	R*8	0000C0	I SFA	L	F	I*4	0000B8	PA S	XR	R*8	000000
PO SF	R*8	000000	DCOS	F XF	POLY	R*4	0000BC	TEIA	FA	R*8	0000C8

**SOURCE STATEMENT LABELS**

LABEL	ISN	ADDR
2	12	000302

## COMPILER GENERATED LABELS

\*LEVEL 2.3.0 (JUNE 78)

OS/360 FORTRAN H EXTENDED

DATE 82.291/17.21.27

PAGE 2

LABEL	ISN	ADDR	LABEL	ISN	ADDR	LABEL	ISN	ADDR
100001	2	00012C	100002	9	0001A6	100003	13	000318

\*OPTIONS IN EFFECT\*NAME(MAIN) NOOPTIMIZE LINECOUNT(60) SIZE(MAX) AUTODBL(NONE)

\*OPTIONS IN EFFECT\*SOURCE EBCDIC NOLIST NODECK OBJECT MAP NOFORMAT GOSTMT XREF NOALC NOANSF TERM IBM FLAG(1)

\*STATISTICS\* SOURCE STATEMENTS = 13, PROGRAM SIZE = 906, SUBPROGRAM NAME = POLY

\*STATISTICS\* NO DIAGNOSTICS GENERATED

\*\*\*\*\* END OF COMPILATION \*\*\*\*\*

\*STATISTICS\* NO DIAGNOSTICS THIS STEP

108K BYTES OF CORE NOT USED

0				
1	1.670	-0.330000		
1	15.000	TMAX,	A,	
0	TMIN,		Z,	WAVE
	3.400000-02	.170000	17.0000	250.000
				.632800

MIE COEFFICIENTS FOR X = 15.00, REF. INDEX = 1.670 -0.3300001  
 QEXT = 2.301859, QSCA = 1.203147 QABS= 1.09871

1	.5064653	.1379551	.4935929	- .1393563
2	.5297321	- .1333192	.4688572	- .1375290
3	.4218656	.1093197	.5840144	- .1159866
4	.6201383	-5.260179D-02	.3652750	5.728591D-02
5	.3773943	-3.309797D-02	.6445963	4.161909D-02
6	.5569460	.1073361	.4301472	- .1392445
7	.5526391	- .1017268	.4207740	.1418122
8	.3944218	-2.740722D-03	.6704453	1.130071D-02
9	.5247071	9.065384D-02	.4612173	- .1773142
10	.5730342	-2.967354D-02	.3153609	6.257319D-02
11	.4821615	-5.544839D-02	.5539805	.2055319
12	.4703139	-7.624024D-04	.7355320	2.459796D-03
13	.4974840	-1.395567D-02	.6255411	- .2345961
14	.4507895	-5.926068D-02	.3904934	- .2867673
15	.3346948	-5.465376D-02	.2040013	- .2025609
16	.1963949	-7.998746D-03	9.664416D-02	-9.772082D-02
17	7.958659D-02	1.648615D-02	3.965646D-02	-3.249231D-02
18	2.165339D-02	1.041643D-02	1.285128D-02	-7.470837D-03
19	4.506663D-03	3.316420D-03	3.253383D-03	-1.199246D-03
20	7.793423D-04	7.671973D-04	6.615229D-04	-1.176307D-04
21	1.152818D-04	1.430563D-04	1.097784D-04	3.746295D-08
22	1.494369D-05	2.242514D-05	1.510305D-05	2.505638D-06
23	1.739678D-06	3.042198D-06	1.769496D-06	5.584542D-07
24	1.850964D-07	3.651073D-07	1.819451D-07	8.143026D-08
25	1.817105D-08	3.936383D-08	1.681650D-08	9.451004D-09
26	1.653388D-09	3.852245D-09	1.419370D-09	9.375439D-10
27	1.397522D-10	3.446746D-10	1.104677D-10	8.232188D-11
28	1.098952D-11	2.834827D-11	7.975826D-12	6.525251D-12
29	8.050636D-13	2.152473D-12	5.363688D-13	4.726311D-13
30	5.502329D-14	1.514330D-13	3.369624D-14	3.153772D-14
31	3.765032D-15	2.726291D-14	2.123833D-15	1.874241D-14
32	.0	.0	.0	.0

XUPP= .10846085  
 XUPP= .65636487

.103512				
.103512	89.9817	-3.67537	88.6206	-8.49324
ARG,	SGN,	SGN2		-5.47233D-02
.103512	1.00000	1.00000		
.116002				
.116002	81.3012	-1.85329	79.7375	-7.54363
ARG,	SGN,	SGN2		-7.15336D-02
.116002	-1.00000	1.00000		
FN	RAD,	E(1),	E(2),	W(K), K
17.6081	3.02140	60.2334	-1.99126	157.664
PSI(1),	PSI(2),	PHI(1)	PHI(2)	-14.7656
				28708.1
				1



.163523	.145850	.196785	.508369				
X(1)	X(2)	ARC	DELT1		BJ1	ATETA	APHI
.108461	.359364	.103512	.0	.0		6.21435	20.5900
		.116(m2)					
X1	X2	Y1	Y2	XX		DELT	PHIM
81.3012	79.7375	-1.85329	-7.54363	-7.16559D-02	-7.15336D-02		.0
	E1(J)	J2(J)					
17.5930	-.718598	86.9103	-8.32932	1			
39.2892	-.895610	69.8086	-6.60429	2			
COLLECTED POWER (P/I).MAX=	2.19990D-08	MIN=	4.51092D-11	MEAN=	1.10221D-08		
VISIBILITY=	.99590738						

## APPENDIX C

### PROCEDURES FOR PSI CALIBRATION AND DATA RECORDING

#### I. Equipment Required

Oscilloscope: Tektronix, Model 7904 or equivalent  
Digital VOM: Data Precision Model 245 or equivalent  
Frequency counter: Hewlett-Packard, Model 5245L or equivalent  
Pulse generator: E-H Research Laboratories, Model 139B or equivalent  
Pulse generator Hewlett-Packard; Model 8007B or equivalent  
Regulated 0-12 VDC voltage source: Lambda, Model LPD 421 or equivalent

#### II. Recording and Playback Components

Calibration of the system begins with the calibration of the recording and playback components. Tape recorder instructions apply to the Honeywell Model 5600 tape recording system equipped with Type 16775816-003 FM record amplifiers and Type 16775395-001 FM reproduce amplifiers. The system records at 60 ips, hence playback at 15 ips requires a 10 kHz filter (Type 1677539-001) inserted in the "A" filter position on the reproduce amplifier card. The calibration is to be performed on the record and reproduce amplifiers for each channel in use. Unless otherwise direct, oscilloscope amplifier inputs are high impedance, DC coupled.

##### A. Record Amplifier

1. Set the recorder POWER and CALIBRATION switches to ON and allow at least five minutes for warm-up. Set SPEED switch and "B" jumper pin (on control panel) to 60 ips. Remove power whenever a printed circuit card is removed or installed.
2. Connect an oscilloscope to monitor the signal at TP1 and TP2 (ground). (TP1 and TP2 are the white and black test jacks at the corner of the record amplifier card.)
3. Remove jumper J2 from the record amplifier card. (Removal of J2 eliminates any signal from the data channel VCO.)
4. Adjust R38 (bias current) for an oscilloscope signal of 500 mV<sub>r.p.</sub> (R38 is the potentiometer closest to TP1.)
5. Install jumper J1 to position C-1. This position is used when the data input is not expected to exceed  $\pm 2.0$  VDC. Position C-2 is used when the signal input is not expected to exceed  $\pm 10.6$  VDC.
6. Install J2 to position C-1. This setting in conjunction with the SPEED switch position selects the proper center frequency for IRIG Wideband Group I.
7. Remove the bias oscillator circuit card from the recorder.
8. Apply a short circuit to the input at the input coaxial connector for the data channel.
9. Adjust R32 (carrier current) for an oscilloscope signal of 70 mV<sub>r.p.</sub> (R32 is the second potentiometer from TP1.) Disconnect the oscilloscope from TP1 and TP2.
10. Connect the frequency counter between TP3 and TP1. (TP3 is located near the card extraction hole.)
11. Adjust R14 (center frequency) to 216,000 kHz. (R14 is the third potentiometer from TP1.)
12. Disconnect the input short circuit and apply + 2.00 VDC to the data channel input.
13. Adjust R3 (deviation from center frequency) for 302,400 kHz. (R3 is the fourth potentiometer from TP1.)
14. Apply - 2.00 VDC to the data channel input.
15. Frequency counter should read approximately 129.60 kHz.
16. Install jumper J1 to position C-2. Apply - and - 10.6 VDC to the data channel input. Frequencies should approximate those for  $\pm 2.0$  VDC.
17. Return J1 jumper to the position C-1. Reinstall the bias oscillator card in the recorder.
18. Remove all test equipment.

AD-A135 632

PARTICLE SIZING IN A FUEL-RICH RAMJET COMBUSTOR(U)  
JOHNS HOPKINS UNIV LAUREL MD APPLIED PHYSICS LAB  
R TURNER ET AL. AUG 83 JHU/APL/TG-1339 N00024-83-C-5301

2/2

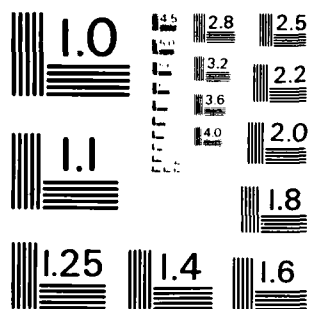
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MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

### B. Reproduce Amplifier

1. Remove recorder power whenever a printed circuit card is removed or installed.
2. Verify that the 10 kHz filter (1677539-001) is installed at the "A" filter position on the card and that the record amplifier has been calibrated.
3. Set the recorder POWER and CALIBRATION switches to ON and allow at least five minutes for warm-up.
4. Set SPEED switch and "A" jumper pin (on control panel) to 15 ips.
5. Apply a short circuit to the input at the input coaxial connector for the data channel.
6. Connect a short jumper lead from TP3 on the record amplifier to TP2 on the reproduce amplifier. (Both test points are near the card extraction holes.)
7. Connect a DCVM or DC coupled oscilloscope to the output coaxial connector for the data channel.
8. Adjust R21 (the only potentiometer on the filter card) for zero volts.
9. Remove the short circuit at the data channel input and apply +2.00 VDC at the input.
10. Adjust R26 (the potentiometer at the corner of the reproduce amplifier) to produce 1.41 VDC at the data channel output connector.
11. Remove the interboard jumper and all test equipment.

### C. Tape Recorder Sensitivity

1. Two levels of sensitivity are provided by installing jumper J1 on the record amplifier to either of two positions. For signals not expected to exceed a peak level equivalent to 2.0 VDC the jumper should be in position C-1. For signals as great as 10.6 VDC the jumper should be in position C-2. Position this jumper in each channel according to the anticipated amplitude of the input signal.

### D. Honeywell Model 1858 CRT Visicorder with Model 1883-MPD Differential Amplifiers

1. Remove power from the unit before removing or replacing any modules.
2. Ensure that the capacitors C3 and C4 have been removed from *all* of the Model 1883 amplifiers. These capacitors are located beneath the metal shield on the printed circuit card. They serve as high frequency filters and their removal is necessary to acquire the widest possible bandwidth.

3. Verify that the J1 jumpers on the printed circuit cards of the amplifiers are positioned for BNC input, normal polarity. There should be a jumper from pin 3 to pin 7 and another from pin 4 to pin 5.
4. Apply power to the Visicorder and allow at least five minutes for warm-up.
5. Each of the Model 1883 differential amplifiers is to be calibrated as described in steps 6 through 13. The sensitivity switch on the front panel indicates calibrated (with TRIM control) deflection per major chart division (5 small divisions of 0.2 in. each) provided that the variable (VAR-CAL) control is set fully clockwise. The VAR-CAL control allows the sensitivity to be set to values that are less than the calibrated steps.
6. Open the paper access door on the Visicorder chassis and release the cradle latch to expose the face of the CRT. Turn the GRIDLINE switch to CONT, set the RECORD SPEED to 0.1 in/s. and depress the DRIVE button. There should be a series of bright spots 0.2 in. apart with every fifth one intensified.
7. On the front panel of the Model 1883 unit, set the controls as follows:
  - a. SENS switch to 0.5 V per division.
  - b. VAR-CAL control fully CW. This control and the TRIM control are 15-turn potentiometers; the POS control is a 22-turn potentiometer.
8. Apply a short circuit to the input coaxial connector.
9. Using the POS control, position the CRT spot associated with this amplifier over a gridline spot near the right side of the CRT.
10. Apply a 2.50 VDC signal to the input of the amplifier and adjust the TRIM control for a spot deflection of 5 major divisions (5 in.).
11. Repeat steps 8, 9, and 10 until there is no interaction between the controls.
12. For deflection sensitivities other than the calibrated positions of the SENS switch, apply a suitable DC signal to the input coaxial connector and adjust the VAR-CAL control for the desired sensitivity.
13. Apply a short circuit to the input coaxial connector and adjust the POS potentiometer for the desired trace position.

## III. Signal Processing Instrumentation

Calibration is accomplished by using a simulated photomultiplier signal supplied by a gated pulse gen-

erator. The simulated signal generator can be adjusted to vary pulse width, amplitude, fringe frequency, and number of modulating fringes. By processing a suitable range of signals, recording the processed signals, and playing them back into the Visicorder, the system output will be known in terms of the input signal and a complete system calibration will result. Unless otherwise directed, oscilloscope inputs are to be high impedance, DC coupled.

#### A. Instrumentation Switch and Control Positions

1. Hewlett-Packard, Model 461A amplifier
  - a. GAIN (DB): 20
2. LRS (LeCroy Research Systems) Model 161 Dual Discriminator (upper unit)
  - a. TERMINATE: 1
  - b. NORMAL - DC PASS: 1 (normal)
  - c. OUTPUT WIDTH: 150
  - d. OUTPUT WIDTH VERNIER: 10.00
3. LRS 161 Dual Discriminator (lower unit)
  - a. TERMINATE: 1
  - b. NORMAL - DC PASS: 1 (normal)
  - c. OUTPUT WIDTH: 15
  - d. OUTPUT WIDTH VERNIER: 4.900
4. Tennelec TC-214 Linear Amplifier and Single Channel Analyzer
  - a. COARSE GAIN: 32
  - b. FINE GAIN: 2.5
  - c.  $\Delta E$ , 0 to 1 V: 5.32
  - d. EI, 0 to 10 V: 8.72
  - e. DELAY: fully counter clockwise
  - f. UNIPOLAR - BIPOLAR: 1 bipolar
  - g. DIR. - INV.: 1 inverted
  - h. L.E. - X.O.: 1 leading edge
  - i.  $\Delta E - E$ : 1  $\Delta E$
  - j. 10V - 1V: 1 1V
5. Ortec 457 Biased Time-to-Pulse Height Converter
  - a. RANGE: 0.4  $\mu$ s
  - b. MULTIPLIER: 1
  - c. COARSE GAIN: 2
  - d. FINE GAIN 0.5 - 1.5: 1.210
  - e. OUTPUT DELAY: fully counterclockwise
  - f. GATE: 1 anticoincidence
  - g. STROBE: 1 internal
6. Mech-Tronics Model 504 Dual Linear Gates
  - a. Verify that R12 has been changed from 2.2 k $\Omega$  to 18 k $\Omega$ .
  - b. GATE WIDTH: fully clockwise
  - c. GATE MODE: 1 NOR

#### B. Simulated Photomultiplier Signal

1. **IMPORTANT!** To avoid calibration errors take the following precautions to eliminate er-

rors produced by signal loading, faulty measurements, and lack of signal symmetry.

- a. Loading the system input signal with a low impedance oscilloscope during calibration and disconnecting the oscilloscope during system operation will produce a large calibration error. The simulated photomultiplier signal should be routed through the TSI photomultiplier terminator 10098 (50  $\Omega$  shunt toward the signal generator) to the 1 M $\Omega$  input of the monitoring oscilloscope and then continue on to the system input amplifier.

- b. Feedback from the system input amplifier tends to make the input signal amplitude difficult to measure with certainty. This problem may be avoided by either of the following procedures.

**PROCEDURE A:** Remove the coaxial cable from the amplifier input and terminate the cable with a 50  $\Omega$  shunt. Set the signal amplitude to the required level, as measured on the oscilloscope, then remove the 50  $\Omega$  termination and reconnect the cable to the amplifier input.

**PROCEDURE B:** Connect a 30 ft (or longer) coaxial cable between the oscilloscope and the amplifier input. This procedure will give a few clean measurable fringes of the input signal before the interference is fed back from the amplifier.

- c. Take care that both the negative-going and positive-going half cycles of the simulated signal are of equal width.
- d. Unless otherwise directed, maintain the amplitude of the signal at 20 mV.
2. Initial system adjustments will be made with a simulated photomultiplier signal consisting of 16 negative-going pulses occurring at a 50 MHz rate. Final adjustments will be made with 16 fringes over the range of 30 to 80 MHz. This range of signals with exactly 16 fringes is produced by varying the frequency and pulse width (to maintain equal negative- and positive-going portions) controls on the HP8007B pulse generator and the width of the gating pulse to the HP8007B. Signals are produced by following steps *a* through *d*.
  - a. On the E-H Research Laboratories, Model 139B, set the controls to produce a positive-going pulse of approximately 4 V, 0.3  $\mu$ s in duration, and occurring once every 0.5 ms. Apply this pulse to the gate input of the HP8007B and to the external trigger of the oscilloscope.

- b. Adjust the pulse-period and pulse-width controls on the HP8007B until the leading edge of the negative-going pulses are exactly 20  $\mu$ s apart and both the negative-going and the positive-going portions are 10  $\mu$ s wide at their midpoints. Adjust the pulse amplitude until the pulses are -20 mV with respect to ground.
- c. Adjust the pulse-width control on the 139B until there are exactly 16 negative-going pulses.
- d. The signal now appearing at the system input is the 50 MHz simulated photomultiplier signal that will be used for most of the calibration; this signal should be monitored with the oscilloscope.

#### C. LRS 161 Dual Discriminator (initial adjustment)

1. Apply the 16 fringe signal to the system input amplifier as described in III.B.1.a.
2. With a 50  $\Omega$  termination at the input of the oscilloscope amplifier, examine the output from one of the upper connectors of discriminator 1 (upper unit). There should be a single negative-going pulse of approximately 1.25 V amplitude and 400 ns duration.
3. Repeat step 2 for the output of discriminator 2 (lower unit). There should be exactly 16 negative-going pulses of approximately 1.25 V amplitude and 10 ns duration. Remove the 50  $\Omega$  termination.

#### D. Peak Sense and Hold

1. Observe the LOW PASS GATE output. Adjust WIDTH G for a positive-going pulse with 0.6  $\mu$ s pulse width. Pulse amplitude should be approximately +5 V. This same pulse should appear at the BANDPASS GATE output.
2. Observe the LOW PASS RESET output. Adjust WIDTH R for a 20  $\mu$ s wide pulse of about +5 V. This pulse should also appear at BANDPASS RESET output and at the GATE and RESET outputs of the TPHC channel.
3. Observe the NEGATIVE GATE output. It should be a negative-going 5 V pulse (from +5 to 0 V) of approximately 0.6  $\mu$ s duration.

#### E. TC-214 Single Channel Analyzer (initial adjustment)

1. Observe the waveform of the MAIN AMP OUT connector. There should be a sinusoidal positive-going waveform followed by a negative-going excursion. Adjust the COARSE

and FINE GAIN controls until the positive-going peak is exactly 9.0 V.

2. Attach a coaxial tee connector at the E1,  $\Delta$ E OUT connector so that the waveform can be observed without interrupting the system interconnections. A positive 6 V, 0.5  $\mu$ s pulse should appear about 2.5  $\mu$ s after the sweep start. If no pulse appears adjust the E1, 0 TO 10 V control to a position that produces a pulse.
3. While observing the simulated signal input to the system, decrease the width setting on the 139B pulse generator until there are only 15 negative-going pulses. If no pulse appears at the E1,  $\Delta$ E OUT connector, decrease the setting of the E1, 0 TO 10 V control until a pulse appears; then slowly turn the control clockwise until the pulse just disappears.
4. Increase the 139B width control to produce an input signal of 17 negative-going pulses.
5. Increase the setting of the  $\Delta$ E, 0 TO 1 V control until a pulse appears at the E1,  $\Delta$ E OUT connector; then slowly decrease the setting until the pulse just disappears.
6. Examine the E1,  $\Delta$ E OUT resulting from input signals of 15, 16, and 17 negative pulses. There should be an output pulse only for the 16-fringe input.

#### F. TC-214 Single Channel Analyzer (final adjustment)

1. Final adjustment of the single channel analyzer (SCA) consists of setting the E1, 0 TO 10 V and  $\Delta$ E, 0 TO 1 V controls so that an acceptance window is created for all 16 fringe signals in the 30 to 80 MHz range and that signals with more or less than 16 fringes are rejected. Because this decision is made on the peak amplitude of a waveform that is available at the MAIN AMP OUT connector, this signal will be measured as the input signal is varied over the operating range of the system; the peak amplitude measurements will then dictate the input conditions for final controls adjustments. This procedure is best illustrated by Table C-1.

The chart shows that the greatest amplitude occurs for a 15-fringe signal (8.8 V) when the fringe frequency is 60 MHz. The lowest amplitude for a 17-fringe signal is 9.5 V at 30 MHz. It is clear that a window whose lower limit is slightly greater than 8.8 V and whose upper limit is slightly less than 9.5 V will accept all

Table C-1

Fringe Frequency (MHz)	Peak Voltage at TC-214 MAIN AMP OUT		
	15 fringes	16 fringes	17 fringes
30	8.5	9.0	9.5
40	8.7	9.2	9.7
50	8.5	9.0	9.5
60	8.8	9.4	9.8
70	8.6	9.2	9.6
80	8.8	9.2	9.8

signals having 16 fringes and reject all others. In this example, the lower limit signal (15 fringes, 60 MHz) is fed into the system and the E1, 0 TO 10 V control is first adjusted for a pulse at the E1,  $\Delta E$  OUT connector. The control is then increased until the pulse just disappears. The upper limit signal (17 fringes, 30 MHz) is then introduced and the  $\Delta E$ , 0 TO 1 V control is decreased until the pulse at E1,  $\Delta E$  OUT just disappears. The adjustments are repeated and proper operation is verified by introducing 15, 16, and 17 fringes at the frequencies in the chart.

2. Prepare a chart such as the one in the example by introducing a simulated photomultiplier signal while observing all of the precautions given in III.B.1. The frequency of the fringes and their symmetry are controlled by the HP8007B and the number of fringes by the width of the gating pulse produced by the 139B.
  - a. Carefully measure and record the positive peak amplitude at the E1,  $\Delta E$  OUT connector for each signal condition. For your convenience the time per cycle for each frequency and the time for a 16-fringe signal (start of first fringe to start of 16th fringe) are listed in Table C-2 below.

Table C-2

Frequency (MHz)	Time per cycle (ns)	Time for 16-fringe signal (ns)
30	33.3	500
40	25.0	375
50	20.0	300
60	16.7	250
70	14.3	214
80	12.5	187

If your chart shows a voltage overlap between acceptable and unacceptable signals, it will be necessary to move slightly the setting of the OUTPUT WIDTH VERNIER on the lower unit (discriminator 2) of the LRS 161 and repeat the chart measurements.

3. Select the upper and lower window limits and make the final control adjustments as in the example of III.F.1.

#### G. Ortec Model 489 Delay Amplifier

1. Observe the output of the amplifier on a DC coupled oscilloscope. A 2 V negative-going signal will appear about 2.5  $\mu$ s after the sweep start.
2. Adjust the DC ADJ until the baseline is at 0 V.

#### H. Ortec Model 457 Time to Pulse Height Converter (TPHC)

1. Apply a 20 mV signal of 16 fringes at 80 MHz to the system input amplifier.
2. Observe the POS OUTPUT with a DC coupled oscilloscope. The positive-going pulse that occurs approximately 4  $\mu$ s after the input signal should be adjusted for a peak amplitude of 9.0 V with the COARSE GAIN and FINE GAIN controls.
3. Adjust the DC ADJ until the baseline is at 0 V.
4. Adjust the signal input for a 20 mV signal of 16 fringes at a fringe frequency of 30 MHz.
5. Adjust the BIAS LEVEL control for a peak positive signal of 1.0 V.
6. Repeat steps 1 through 5 until the output conditions are met without further adjustment of the TPHC controls.

#### I. Mech-Tronics 504 Linear Gate (low pass channel)

1. Apply to the system input a 16-fringe, 50 MHz, 20 mV signal.
2. With a DC coupled oscilloscope view the waveform at the SIG. OUT connector. It should be a rectangular pulse 18 to 20  $\mu$ s in width and approximately 100 mV in amplitude.
3. Vary the input signal amplitude between the values of 20 and 40 mV. The pulse amplitude should rise and fall in step with the input variations.
4. Change the input signal to 15 fringes, then 17 fringes; there should be no signal output in either condition.



**J. Mech-Tronics 504 Linear Gate (bandpass channel)**

1. Repeat steps I.1-4.

**K. Mech-Tronics 504 Linear Gate (TPHC channel)**

1. Apply to the system input a 16-fringe, 50 MHz, 20 mV signal.
2. With a DC coupled oscilloscope, view the waveform at the SIG. OUT connector. It should be a rectangular pulse 18 to 20  $\mu$ s wide and approximately 6 V in amplitude.
3. Change the input signal to 15 fringes, then 17 fringes; there should be no signal output in either condition.

**IV. Complete System Calibration**

The complete system calibration is accomplished by applying known signals to the system input amplifier, recording the processed signals on the Honeywell 5600 tape recorder, sending the reproduced signals to the Honeywell 1858 Visicorder, and relating the printed Visicorder output to the system input signal.

**A. Preliminary Instructions and Precautions.**

1. Ensure that the filter circuit (1 k $\Omega$ , 2000 pF) is properly connected between the linear gate outputs and the HP5600 recorder inputs.
2. Ensure that jumper J1 in the record amplifier of each record is in the correct position for the anticipated signal. See paragraph II.A.5. Signals that exceed the specified maximum (2 or 10.6 VDC) will produce an erratic output from the recorder making the Visicorder traces unintelligible.
3. It is especially important that the simulated photomultiplier signal precautions of Section III.B be strictly observed.
4. During the remainder of the calibration, the gating signal is removed from all three of the Model 504 Linear Gates, and their GATE MODE switches are placed in the BLOCK position. Upon completion of the calibration, the gating signal is restored and the GATE MODE switches returned to NOR.
5. Warm up all equipment at least 5 minutes before proceeding.

**B. Low Pass and Bandpass Channels (tape record)**

1. On the tape recorder, set the SPEED switch

and "B" jumper pin in the 60 ips position.

2. Monitor the inputs of both data channels to the recorder.
3. Apply a 16-fringe 50 MHz signal to the system input amplifier and lower the signal amplitude until there is no change in the signal level to the recorder. This will occur when the input signal is at approximately 15 mV peak and this level becomes the lower limit of the calibration range. The upper limit is the level that produces a saturation in the system input amplifier; this level occurs slightly beyond 700 mV. Select signal levels at and between these extremes to provide a reasonable number of calibration points. Suggested values are 15 mV (or lower limit signal), 20, 30, 40, 50, 100, 150, 200, 250, 300, 400, 500, 600, and 700 mV.
4. For each value selected proceed as follows:
  - a. Depress the D (drive) button to start the tape motion, and when the PL light near the POWER switch comes on, depress both the D and the REC buttons and note the reading on the tape footage indicator.
  - b. When the tape footage indicator has increased by approximately 30 ft, note the indicator reading and depress the STOP button.

**C. Low Pass and Bandpass Channels (tape playback and Visicorder chart record)**

1. Position the traces of the Visicorder and adjust their sensitivities so that they are not apt to interfere with each other. Unused traces can be eliminated by placing the 1883 amplifier sensitivity switch in the OFF position.
2. Set the Visicorder chart speed at 4 ips.
3. On the tape recorder, set the SPEED switch and the "A" jumper pin to 15 ips. Position the tape so that the footage indicator reads a value lower than the beginning point for the calibration recording that is about to be fed to the Visicorder.
4. Depress the D button on the tape recorder and watch the footage indicator. When it approaches the midpoint of the recording range for that calibration point, depress and lock the DRIVE button on the Visicorder.
5. After 2 seconds of Visicorder operation, depress the DRIVE button to unlock it and press the STOP button on the tape recorder.
6. Repeat this procedure for each calibration point.

**D. TPHC Channel (tape record)**

1. On the tape recorder set the SPEED switch and "B" jumper pin to 60 ips.
2. Monitor the input to the recorder from the TPHC data channel.
3. Apply a 16-fringe, 30 MHz, 20 mV signal to the system input. A signal of approximately 1 V should be present at the recorder input.
4. Record the signal as in IV.B.4.
5. Repeat this procedure with 16-fringe signals of 40, 50, 60, 70, and 80 MHz.

**E. TPHC Channel (tape playback and Visicorder chart record)**

1. Follow the procedure of IV.C. to produce a Visicorder chart record for the TPHC frequency related outputs.

The calibration is complete when the output amplitude of the Visicorder is plotted against the signal amplitude or frequency producing that output. Restoring the gate input to the Model 504 Linear Gates, placing their GATE MODE switches to the NOR position, and reconnecting the photomultiplier through its termination (TS1 10098) to the system input amplifier restores the system to its normal operating configuration.

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**PARTICLE SIZING IN A FUEL-RICH  
RAMJET COMBUSTOR**

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